MILITARY BRIDGING

MR Joshi

Defence Research & Development Organisation
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MILITARY BRIDGING

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CONTENTS

Preface *xi*
Acknowledgement *xv*

CHAPTER 1: HISTORICAL BACKGROUND **1**
1.1 Introduction 1
1.2 Bridges – The Beautiful Monuments 2
1.3 Impact of Industrial Revolution 3
1.4 The History of Military Bridging 5
1.5 The Change in Scenario 8
1.6 The Indian Context 9

CHAPTER 2: COMBAT ENGINEERING **11**
2.1 Background 11
2.2 Combat Missions 11
2.3 Fighting Positions 12
2.3.1 Trenches 12
2.3.2 Foxholes 12
2.3.3 Revetments 12
2.3.4 Bunkers 12
2.4 Countermobility Devices 13
2.4.1 Simple Obstacles 13
2.4.2 Abatis 13
2.4.3 Mines 14
2.4.4 Concertina Coil 14
2.5 Offensive Operations – Mobility 15

2.5.1 Bridging 15
2.5.2 Breaching Minefields 15
2.5.3 Clearing Obstacles 15
2.6 Obstacle Planning 16
2.6.1 Intelligence 16
2.6.2 Logistics 16
2.6.3 Fire Support 16
2.6.4 Engineers 17
2.7 Planning Considerations 17
2.7.1 Offensive Considerations 17
2.7.2 Defensive Considerations 17
2.8 Obstacles 17
2.8.1 Obstacle Categories 17
2.8.2 Obstacle Effects 18
2.8.3 Obstacle Control Measures 19
2.8.4 Situational Obstacles 20
2.8.5 Conventional Mine Categories 21
2.9 Crossing Means 21
2.9.1 Description of Crossing Means 22
2.10 Combat Engineering in the Indian Subcontinent 23
2.11 Conclusion 25

CHAPTER 3: TYPES OF MILITARY BRIDGES 27
3.1 Background 27
3.2 The Pioneers 28
3.3 Methods of Crossing Obstacles 30
3.3.1 Fords 30
3.3.2 Ferries 32
3.3.3 Types of Military Bridges 35
3.4 Ancillary Equipment 35
3.5 General Considerations 38
3.6 Mines and Obstacles 40
3.7 River-crossing Operations 40

3.7.1 Hasty River-crossing 41
3.7.2 Deliberate River-crossing 41
3.7.3 Tactical Bridging 41
3.8 Conclusion 41

CHAPTER 4: DESIGN OF MILITARY BRIDGING EQUIPMENT 43
4.1 Introduction 43
4.2 Military Bridging – Design Criteria 44
4.3 Guidelines for Design 45
Appendix A: Broad Guidelines for Design of Military Bridges 47

CHAPTER 5: INTEGRATED LOGISTICS SUPPORT 131
5.1 Background 131
5.2 Make or Buy 131
5.3 Indigenous Equipment 132
5.4 Defect Reports 132
5.5 Failure Mechanism and Criticality Analysis 133
5.6 Maintainability of Equipment Imported from Abroad 133
5.7 Integrated Logistics Support 136
5.7.1 Maintenance Planning 138
5.7.2 Manpower and Personnel 139
5.7.3 Supply Support 140
5.7.4 Support Equipment 140
5.7.5 Technical Data 140
5.7.6 Training and Training Support 141
5.7.7 Design Interface 141
5.8 Conclusion 142

CHAPTER 6: THE BRIDGING EQUIPMENT WORLDWIDE 143
6.1 Infantry Bridges 144
6.2 Evolutionary Development of Bridges 145
6.3 Bridges of Cold War 147

6.3.1 Armoured Vehicle-Launched Bridges – Introduction 148
6.4 River-crossing 148
6.5 Improved Float Bridge - Ribbon Bridge 150
6.5.1 Considerations for the Tactical Employment of Ribbon Equipment 150
6.5.2 Site Selection 150
6.5.3 Raft and Bridge Sites 150
6.5.4 Water Depth (draft) Restrictions 150
6.5.5 Bank Restrictions 152
6.5.6 Current Velocity 152
6.5.7 Launch on High Banks 152
6.6 Interior Bay 153
6.7 Ramp Bay 153
6.8 Bridges and other Expedients 154
6.9 Bridges of World War II 154
6.9.1 Manually Launched Bridges 157
6.9.2 Details of Armoured Vehicle Launched Bridges 162
6.9.3 Wheeled Vehicle-mounted Bridges 163
6.9.4 Floating Bridges 166
6.10 Military Bridges for Civil Applications 169

CHAPTER 7: RELEVANT TECHNOLOGIES 175
7.1 Background 175
7.2 Performance Improvement Factors 176
7.3 Anatomy and Stowage 176
7.4 Mechanisation and Automation 177
7.5 Efficiency of the Design 179
7.6 Selecting New Materials 180
7.7 Members in Compression 186
7.8 Members Subjected to Repeated Loadings 187
7.9 Load and Resistance Factor Design 187
7.10 Composites – A Material of the Future 188

7.10.1 What's a Composite? 189
7.11 Members in Compression 190
7.11.1 Design - Comparison with other Structural Material 192
7.12 Concurrent Engineering and Application of Information Technology 197
7.12.1 Understanding Customer Requirements 199
7.13 Conclusion 201

CHAPTER 8: MILITARY BRIDGE CLASSIFICATION SYSTEM 203
8.1 Background 203
8.2 Indian Environment 204
8.3 The System and its Application 207
Appendix B: The Military Load Classification System and its Application for Indian Army and Civilian Codes of Practice 210

CHAPTER 9: THE FUTURE 241
9.1 Lessons Learnt During Recent Wars 241
9.2 Revolution in Military Affairs 244
9.3 Dominating Manoeuvre 246
9.3.1 New Bridges for a New Century 247
9.3.2 Wet Bridging 248
9.3.3 Rapid Deployment of Military Bridges 249
9.3.4 Military Bridging – Organisational Issues 250
9.4 Future – The Indian Sub-continent 251
9.5 Conclusion 253
Glossary 255
Index 259

PREFACE

Mankind has seen wars from the times immemorial. The twentieth century saw some of the worst faces of war when millions of innocent civilians were killed. In recent years, fourth dimension have been added to the war – War in Space. Many wars are waged to save the human life; yet century after century, the wars have become more and more fierce. Even in the twenty first century, armed conflicts are going on in some parts of the world. When we read about the nuclear doctrines, theater nuclear weapons, national missile defence etc., an impression gets created that the age-old weapons have lost their place.

In the pre-historic times, obstacles were being negotiated by using bridges. Ramayana and other Biblical stories clearly indicate use of crossing methods for negotiating obstacles. The history of military bridges can be traced back to those times. Coming straightaway to the twentieth century World Wars, the emergence of the battle tank on the field brought the need for innovative bridging solutions. The famous Bailey bridge is the popular name for any military bridge as far as the common man is concerned. The Bailey bridge had a major impact on the mobility of the battle tanks and progress of the war during the 1940's. Without the Bailey, the successes in Europe and Italian and African fronts by the allied forces would not have been possible.

The Indian armed forces, and particularly the Indian Army carried on the British legacy and thus inherited a large inventory of the Bailey bridge. Even the 1971 Bangladesh war was fought with such equipment. It was only after this war that the bridging equipment from different sources started flowing in. The first to arrive was the Soviet equipment developed

by Russians during the Cold War days. The family of the bridging equipment was very much different from the second World War equipments. In fact it reflected the East Europe's experience in the European theater, primarily for river-crossing. The Indian Army also found such equipment very effective for assault crossing of canals in the western theater. The equipment found its use; but was used for purposes other than what was written in the handbooks. Thus, the handbooks started being 'rewritten' by the field commanders without getting them issued by the higher authorities. After all, what gets proven during the exercises is accepted for working out the tactics. After the induction of a variety of combat engineer equipment from the Soviets, the doors were opened to other equipments coming from Germany and the United Kingdom. Although the manuals and handbooks were well prepared, these were primarily for international market. Therefore, these were not comprehensive to cover the contemplated obstacle pattern on the dynamic Indo-Pak border and the equipment planning and deployment.

Soon after the partition, the obstacle pattern on both sides of the Indo–Pak border got totally changed. Several hundred kilometer of unnatural manmade obstacles were added to the existing network of irrigation canals. There were canals of different widths and slopes of the banks. There were high bank canals, which offer a formidable obstacle – almost non-negotiable. In addition to long and medium spans, there are short spans, which pose certain problems for negotiation of standard equipment. The Army therefore, has to continuously improvise and innovate using the existing equipment. Although the field applications go much beyond the equipment handbooks, no authentic manual has been written on the subject. The second World War saw the publication of the first edition of Military Engineering brought out during the progress of the war itself. Soon after the conclusion of the war, an urgent need was felt to rewrite this publication taking into account the rich experience of the War. Thus, came the Military Engineering, Vol III in 1957 by the War Office, London. The Indian Army brought out a reprint of this publication in 1968, which made some changes in the military bridge classification system without even mentioning the changes. As a result, a dual classification number for the equipment came into existence, creating a

good amount of confusion. Even though NATO has addressed such problems through the standard agreements, the situation on the Indian side has not changed. Therefore, a need was felt to add chapters on the military bridge classification systems and the design methodology to be followed for the equipment bridges. Over the years, considerable changes have occurred in the field of new age materials. The reader will find useful references to the weldable and self-ageing aluminium alloys and composites.

There is a good number of military publications from the reputed publishers like the Janes. Periodically, special issues/compendium are brought out on specialised subjects. These includes the latest developments in the field of equipments related to combat engineering. However, these at best can be considered as catalogues. Sometimes, these also serve as an advertisement for the multi-nationals, who are always looking for foreign military sales. The purpose behind writing this Monograph is altogether different and is generally in line with the DRDO policy of bringing out publications to a wide spectrum of readership at reasonable cost.

The author, having worked in all the aspects of the life cycle of a typical military bridge for over 35 years, thought that there was a void in the field of published material related to combat engineer equipment, and hence this Monograph. The author does not claim that it covers the subject comprehensively, but, it is a modest attempt to make a beginning.

On the background explained above, the Monograph can be considered as a quick guide and reference material for engineers from different disciplines. For Military Engineers, it can serve as an additional reference material to the 'Mlitary Engineering, Vol III'. For the users and for the construction industry and highways, it will provide vital design requirements and details. The chapters on design and military bridge classification system can fill up the gaps between the obsolete tables that are referred today. For material technologists, it can provide unique opportunities for design in aluminium alloys and composites. For the institutes and organisations including NGOs and the private/

public sector engineering industry, it can provide vital clues as to how military obstacle crossing is similar to any disaster management exercise. After all, without earthquakes, we hear so frequently the collapse of civil bridges and flyovers as also accidental failure of multi-storeyed buildings in the urban areas. Floods, cyclones, and tsunami are commonly experienced as annual events. The Army is called upon to provide help with the equipment that they can harness. If proper disaster mitigation machinery was in place, it could have acquired and stocked specially designed equipments to provide quick solutions to the problem. This can have a major impact on the minimisation of loss of life and property. In fact, the Indian Railways have emergency bridges named as 'relieving girders', which are authorised to be held by each division. All concerned with the above activities may find this Monograph quite useful.

With all that I have covered in this Preface and the subsequent chapters, there may be quite a few deficiencies and errors. After all, this is the first ever attempt and there was hardly any publication to fall back upon. The author will be grateful for the readers' suggestions and even criticism; because that's how the life is! Right from our childhood, we fall, learn and improve! At the age of seventy, I can still learn. After all, learning is a continuous process.

I would like to end this Preface with a quote from the famous military engineer – Leonardo da Vinci, who recorded the following in one of his notebooks:

While I thought that I was learning to live
In fact, I was learning to die!

Delhi — Madhukar R Joshi

31 January 2008

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The author would like to place on record the help and assistance provided by quite a few individuals and organisations. Without such a support, it would not have been possible even to make a start to write this Monograph. Firstly, I would like to place on record my sincere gratitude to Mr Ved Prakash Sandlas, the former Chief Controller, DRDO, who against all odds, insisted that I should take on this task. The manner in which he put the proposal for approval proved to be the primary motivating factor for me to accept the assignment. The Directors, DESIDOC, especially Dr Mohinder Singh and later, Dr AL Moorthy gave me spontaneous support with any amount of reference material that was asked for. For the content, the knowledge I acquired over a long period of time from different sources from India and abroad was crucial. The insights in military bridging obtained from the Military Vehicle and Engineering Establishment (MVEE), Christchurch, UK have proved to be quite handy throughout my career. Needless to say that this trickled down in different form in my Monograph.

While I spent several months in the field areas, ranging from the North-East to Northern and Western borders, I had an excellent opportunity to work hand-in-hand with the engineer regiments and the troops. The innovative way in which Brig Sundaram carried out his training programmes and exercises, had a lasting impression upon me as to the exploitation of the equipment. The Engineer-in-Chiefs, right from Lt Gen VN Kapoor to Lt Gen Sinha as well as senior

general officers including Lt Gen Taneja, Lt Gen YV Pandit, and Lt Gen Ashok Joshi were military thinkers and a close association with them helped me to understand the operational situations and tactics.

The Directors of R&DE(Engs), right from late Brig AC Aga to my successor late Mr YP Pathak, gave me excellent support. Especially, Lt Gen TC Joseph and Lt Gen RVN Kadambi groomed me in my young days, which helped me to get deeply involved in the total life cycle of a military bridge. The present Director, Mr B Rajagopalan and his excellent team has always been interacting with me and helping me to keep update with latest developments in the field. I am indebted to all these knowledgable persons without whose guidance this Monograph could not have come out. I am also extremely grateful and acknowledge the help rendered by the US Department of Defense – Army RDECOM for giving copyright clearance for Trilateral Design and Test Code for Military Bridging and Gap Crossing Equipment document.

And finally, it is my duty to acknowledge the contributions of Mr A Saravanan and Ms Kavita and their dedicated team for extending valuable support in preparing the manuscript, compilation of graphs and tables and making valuable suggestions so as to make this publication as flawless as possible.

CHAPTER 1

HISTORICAL BACKGROUND

1.1 INTRODUCTION

From the time immemorial, the man has been engaged in conflicts of different nature. With the advent of civilisation, this tendency never died down; on the contrary for the sake of greed, acquiring scarce resources or for satisfaction of one's ego, these conflicts have grown in size, intensity, and fierceness. With new materials becoming available to the man, there has been every attempt to convert these discoveries into strength that can prove to be the single most winning factor in any battle. The need for solid defence against these weapons was the natural corollary to the destructive power of these weapons. Equally important was the defence preparedness to protect oneself from the military might of the enemy. The rivers and other geographical features became natural boundaries for the ancient rulers since these were not easily negotiable.

The great Indian epic *Ramayana* gives a vivid account of bridging the gap between Rameshwaram and Sri Lanka across the Indian Ocean. The crucial bridge built manually across the ocean by the *Vanarsena* (Simian army) was not only instrumental but also essential for *Sri Ram* to defeat *Ravana* and liberate *Sita*. Researchers of the 20th century studied the ocean bed characteristics through aerial survey at the place where the crossing was achieved and found that though the water depth was shallow, yet not negotiable. The site was therefore converted into a ford with relatively little effort. The *sena* could then cross over to Sri Lanka comfortably.

In Biblical stories, there have been references to crossing of rivers in Central Asia, such as Euphrates. Later, Alexander the Great is known to have moved his troops across Euphrates. Mesopotamia is known to be the

cradle of civilisation; and in Greek, the word Mesopotamia means the land between two rivers, i,e., Tigris and Euphrates. For thousands of years it has been a setting for strife on a grand scale as powerful regimes toppled and replaced each other. One such world-shaking event took place near the northern Iraqi city of Arbil on October 1, 331 BC. It was a conflict of a global proportion, pitting West against East, Europe against Asia. Persia was the most powerful empire in the world at that time, and Babylon, its capital, was the world's richest city. The empire stretched from the Mediterranean Sea, including Egypt, encompassing most of what we today call the Middle East. The Persian emperor Darius III massed his huge army against the invading Macedonians of Alexander the Great. After crossing the Tigris river, Alexander the Great sent a letter to Darius saying, "*If you dispute the kingship of Asia with me, stand and fight* ". Although Alexander was greatly outnumbered, the tactics and fighting spirit of the Macedonians prevailed. The Persian army was routed, and Darius had to flee in disgrace. Meanwhile, Alexander crowned himself as the king of Asia. He was only 25 year old then, and in the following years, he extended his conquests to the Hindu Kush mountains of Afghanistan and the Indus Valley of northern India. The ancient land between the rivers, however, was conquered and reconquered many times in the centuries that lay ahead. The crossing of Tigris and Euphrates came into focus even in the 21st century, when the coalition forces had readied their improved Ribbon bridge for the crossing operations to march towards Baghdad.

This chapter intends to introduce the reader the basic concept of military operations related to combat warfare, obstacles, and the need to have a quick solution for crossing such obstacles.

1.2 BRIDGES – THE BEAUTIFUL MONUMENTS

The bridges built as early as 2000 years ago are still existing in the world. The author himself has visited a 13th century bridge, Ponte Vecchio in Florence, Italy. This bridge even today is surrounded by a market place and is in regular use. These bridges were basically civilian structures. Apart from strength and the other essential requirements, one striking feature of the ancient bridges was the aesthetics and architectural beautification that was an integral part of the bridge design. Later, as the renaissance was

sweeping the western world, Leonardo da Vinci conceived new designs that primarily had military applications. In fact, he could get an entry in the Court of the Duke of Milan through his letter that had the new concepts for light and portable bridges for military applications at the top of the agenda. There are several pages in his notebooks devoted to the description and drawings for such bridges. Figure 1.1 depicts one of these concepts.

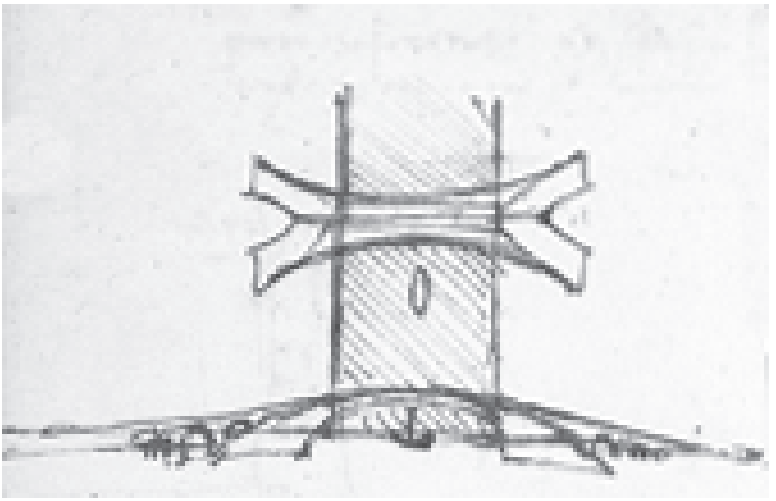

Figure 1.1. One of the sketches of bridges conceived by Leonardo da Vinci.

What is remarkable is that even after 500 years, the scientists and engineers are trying to appreciate the innovation behind these concepts. It was no surprise that the Norwegian Government converted one of his concepts into an actual bridge in the year 2002. This bridge is shown in Fig. 1.2. This project was aptly announced as Bridging Project 500 years behind schedule.

1.3 IMPACT OF INDUSTRIAL REVOLUTION

Soon after the industrial revolution had swept Europe in the 18th century, the impact of these developments on the battlefield started becoming obvious. The developments in the field of military engineering after the industrial revolution must be credited to the European competitors such as Britain, Germany, and France. The two world wars fought during the first-half of the 20th century are the worst examples of this technological race in which over 50 million lives were lost.

Figure 1.2. Leonardo's bridge concept implemented in Norway 2002.

Towards the last decade of the 19th century, the technological advances in internal combustion engines, automobiles, railways, telegraph, and radio started influencing the battlefield in an unprecedented manner. The land war was greatly influenced by the progress in automotive technology, which brought a new weapon in the battlefield – the battle tank. Once the battle tank was designed and produced, there was an urge to use it in the battlefield without even evolving proper doctrine. The following incident from the *Battle of Cambrai* will prove this point.

On November 20, 1917, the British army planned a major surprise attack on the German positions at Cambrai using for the first time a combination of infantry, artillery, battle tank, and reconnaissance aircraft. At about 0610 hrs, the throb of tank engines, which numbered 465, filled the air to be soon drowned in the noise created by the low-flying aircraft. The tanks made an impressive advance of four miles in the first hour, leaving the fellow infantrymen as well as the Germans totally surprised. But as they reached the vital bridge across the Escaut canal, under the first tank crossing itself, the existing bridge collapsed, just because it was simply

not designed to carry the tank load. No portable bridging equipment was available, just because it did not exist. The *Battle of Cambrai* ended in stalemate amid winter gloom. The technological surprise of the battle tank was lost by just one fact that the requirement of appropriate military bridging equipment was not considered simultaneously with the deployment of the tank as a new major weapon of the future.

Between World War I & II, considerable debate was generated amongst the military planners to use air power and battle tanks to dominate the battlefield. Yet, the May 1940 campaign launched by the Germans across the French territory (popularly known as Blitzkrieg) using Panzers took everyone by surprise. The success and the dramatic results even stunned the Germans. As a spontaneous response, the British churned out of the Royal ordnance factories, new families of tanks, which were slowly getting heavier and heavier. With the induction of tanks by the Allied forces, the need for finding new solutions to the obstacle and river-crossing problems was felt as never before. Bailey bridging made an immense contribution towards fulfilling this need. The speed and tempo of forward movement, that was so crucial to the Allied forces' victory in Italy and north west Europe, could never have been maintained without large supplies of Bailey bridging.

1.4 THE HISTORY OF MILITARY BRIDGING

The history of military bridging will never be complete unless one acknowledges the pioneering work by the Royal Military Engineers over the last century. It is true that the new technologies unleashed by the industrial revolution were mainly the root of all such developments planned and executed at the Experimental Bridging Company, Royal Engineers, UK. But the importance of innovation behind these developments cannot be overlooked.

In the history of modern warfare, there are quite a few river/ obstacle-crossing operations that have become so famous that they can never be forgotten. Crossing of Normandy in the English Channel, negotiating Rhine in Germany, the Italian Campaign, and the Bridge on River Kwai are some of the examples to prove this point. Out of these, the Bridge on River Kwai came to fame through a French novel, which was an

adaptation of the actual story. This novel was adapted further to produce a film of the same name. It became so famous that the film won a record number of Oscar awards for the year 1957.

Leaving aside this aspect of the military bridges, the types of bridges that surfaced during the World War II were as diverse as amazing. The modular aspect of the Bailey offered many solutions to the obstacle-crossing using a single family of equipment (Fig. 1.3). Thus, emerged the Bailey bridges from single-single to triple-double constructions, later covering rafts and pontoon bridges and even suspension bridges. It was

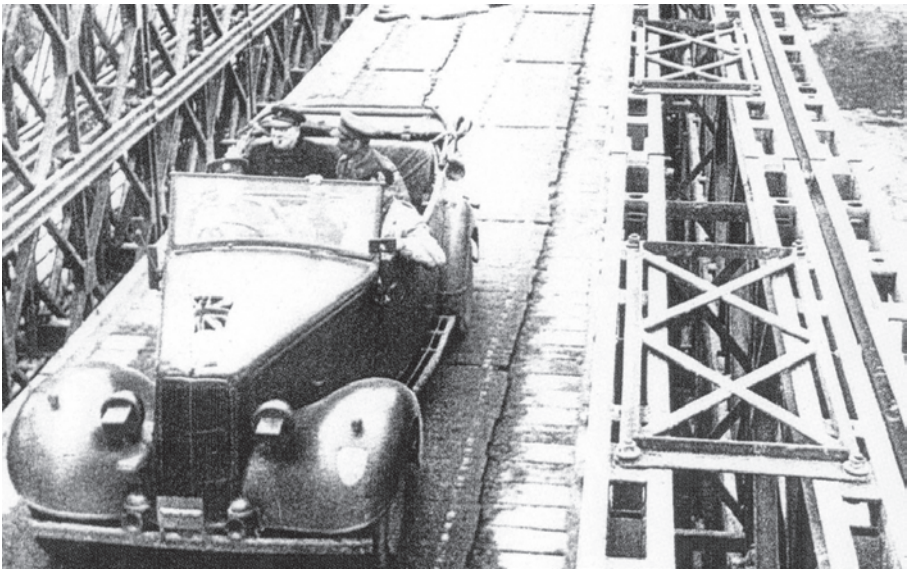

Figure 1.3. Bailey bridge being negotiated by Sir Winston Churchill (erstwhile British Prime Minister) during the World War II.

amazing that just one family of bridges could provide a universal solution to practically every obstacle-crossing problem. Dry gaps, rivers, canals, chasms, and ravines did not make any difference to the user. He had only to select proper combination from standard components of the bridge, which have now mounted to several hundred in number.

The end of the war saw some discontinuity in bridge development, but the Communist countries under the leadership of the Soviet Union saw to it that their backwardness in this field during the war years was more

than made up by their innovation. Although mechanically launched bridges mounted on a tank chassis had started cropping up from the Western European countries during the war itself, the Soviets brought in new concepts of folding Pontoon bridges, trestle-cum-span bridges, and bridge layer tanks (BLTs). It was a silent revolution taking place in the field of military bridges and India became one of the many countries that imported some of these equipment soon after the Indo-Soviet Treaty was signed in 1971. The Pontoon bridge was so innovative in design that it took the Israelis by surprise, when on the festive Yom Kippur day, the Egyptians surprised their enemies by a quick crossing of Suez canal and crossing the Bar Lev line. This equipment attracted the attention of the western world which quickly copied the design from the satellite photographs that were made available to them in 1978. Thus, came the Ribbon bridges from USA, Germany, France, and UK, all of which were essentially the copies with some changes made in the material specification.

In 1971, Bangladesh War (popularly known as the Engineers War) was fought by India mostly using the Bailey of World War II vintage. By 1965, the Indo-Pak border on the western front was strewn by several hundred kilometre of the man-made obstacles – the technique now popularly known as Ditch-cum-Bund (DCB). This ensured that there were no major thrusts inside the enemy territory on both the sides as in the previous wars. In addition, the age-old irrigation canals already existing in the border states of Punjab and Rajasthan also provided a natural obstacle. Crossing of Icchogil canal during 1965 using Bailey bridging equipment made an excellent war story. However, none of the operations conducted on the western frontiers can be considered as a model obstacle-crossing plan for winning a battle on either side, especially in a modern war. Twenty first century warfare cannot be fought with 20th century technologies and equipment.

On the eastern frontier, however, it was a different story for river-crossing operations. Although the equipment was the same good old Bailey, India could achieve complete air superiority in the first four days itself. Thereafter, construction of Bailey bridge over the formidable Brahmaputra river posed no problems. The troops and the

logistic supplies could be transported freely over these bridges and the war was over within 12 days.

Although the terrain and the obstacles in the Indian subcontinent would not undergo major transformation over the decades, the modern war has demanded improved capabilities since the obstacles now could be dynamic. There could be minefields and the terrain could be flooded by releasing water and breaching some portions of the canals. The water level in the canals could also be varied through upstream controls that would render the obstacle temporarily unmanageable, since the floating bridges need certain depth of water and have limitations on the heights of the banks. The speed of the water current could also restrict use of many standard bridging equipment.

1.5 THE CHANGING SCENARIO

The end of the cold war has made little difference to the engineering operations in the Indian subcontinent, especially the Indo-Pak border. But globally, there are major changes brought in by change in doctrines and tactics that make a major impact on the role of army engineers in negotiating the obstacles.

Since 1990's, the focus of US military operations has shifted from Europe to areas of the globe with fewer broad rivers, and the technique of fighting has shifted from the deployment of massive ground forces to heavy reliance on air power, making river-crossing somewhat less important.

In the 1991 Persian Gulf War, US forces had no need to cross any major river. Yet the need to bridge longer obstacles by heavier tank – M1A1 exposed the shortcomings in the available bridging equipment. Thus, the abandoned programme of developing a new family of bridges in the 1980's, got revived through the development of Wolverine, the 26 m sliding bridge mounted on M1A1 chassis.

The next time US ground forces crossed a major river under conditions that might have led to combat was in Bosnia-Herzegovina in 1995. The crossing of the Sava river was unopposed; yet it was severely complicated by the worst flooding of the river in 70 years. Few

Commanders involved had executed a major river operation, even in training. Even so, US forces were so confident about the operation that they ferried troops and equipment across in helicopters and rafts much before the bridge was completed. But still, there were a lot of things that needed to cross the river that could not be airlifted. After almost a week of attempts, army engineering brigades built a 373 feet one-lane span in 72 hrs.

Getting an armoured force, even a relatively light force, across a river is anything but simple. Although every ground unit is trained and outfitted to get troops and equipment across small rivers, creeks and gaps, crossing a major river is a different challenge altogether. Although many aspects of waging a war have got easier with the advent of modern technology, crossing a river has in some respects become harder, because a modern army has so much equipment to move. Although technology has made it possible for the modern army to protect its forces with air power as it unfurls bridges off the backs of trucks, the fundamentals of attacking an enemy across a river have not changed since ancient times, when the Persian army built bridges in the 5th century BC during its invasion of Greece, and ancient Macedonia. It has always been the job of professional engineers to achieve or speed up a difficult river-crossing.

River-crossings are technically difficult feats of amazing technology and skill. To get vast amoun`ts of heavy equipment across a major river, that can't be brought in by air, one needs to worry about currents, muddy banks, steepness of the banks, and depth of the water. It's never been easy.

1.6 THE INDIAN CONTEXT

In the Indian subcontinent, however, the creation and negotiation of obstacles has assumed unprecedented importance. The border region, though having restrictive terrain, has not always prevented conflict between India and Pakistan. Rather, in successive conflicts, there has been clearly a strong desire to capture the territory across an obstacle to get some bargaining advantage after the ceasefire.

The Rann of Kutch, where logistical support is limited by climate and sparse road network, the Great Indian and Thar desrets, and the Siachen glacier in the Karakoram range have all witnessed major conflicts in the past. Whatever happens to the global scenario, these ground realities will not change, necessitating the two countries to have their own solutions to the obstacle-crossing problems. India clearly stands to an advantage in such situations because of excellent technological and industrial base. Add to this, the strong research and development infrastructure, one can now can work out force-multiplier solutions through unique obstacle-crossing solutions.

This Monograph is therefore prepared on the above backdrop. The reader may find some commonalities with the traditional handbooks and manuals on military bridging; yet at many places it will depart from those standard compilations to ensure that the focus remains on the requirements and developments in the Indian subcontinent. For the matter of well laid out procedures, recorse has been taken to get the information from open source, especially from the field manuals of the US DoD.

CHAPTER 2

COMBAT ENGINEERING

2.1 BACKGROUND

Combat engineering is an integral part of the ground troops' ability to manoeuvre. Combat engineers enhance the troops' momentum by physically shaping the battlespace to make the most efficient use of the space and time, necessary to generate mass and speed while denying the enemy unencumbered manoeuvre. By improving the battlespace, combat engineers accelerate the concentration of combat power, increase the velocity and tempo of the force necessary to exploit critical enemy vulnerabilities. By reinforcing the natural restrictions of the battlespace, combat engineers limit the enemy's ability to generate tempo and velocity. These limitations increase the enemy's reaction time, and physically and psychologically degrade his will to fight.

2.2 COMBAT MISSIONS

The mission of the combat engineer is relatively simple, and consists of two basic concepts, (i) counter the mobility of the opposing forces while enhancing the manoeuvre capabilities of own forces, (ii) increase the defensive capability of own forces through fortifications, while reducing the enemy defensive strength by destroying their fortifications. Military operations in hazardous or unusual environments also form a large part of the combat engineer duties.

2.3 FIGHTING POSITIONS

2.3.1 Trenches

Trenches are the most primitive and basic defensive fortification, and also remarkably effective. Trenches provide cover and concealment for personnel, while allowing movement between more fortified fighting positions. Dozers, scrapers, combat engineer tractors (CETs), explosives, and hand tools are all used to create trenches. Trenches can range from simple slit trenches suitable for a single occupant, to extensive networks of high traffic corridors with overhead cover. Trenches that are wide and deep enough, pose a significant obstacle to traditional wheeled or tracked vehicles. If constructed for that purpose, these trenches are referred to as ditches.

2.3.2 Foxholes

Similar to trenches, foxholes are simply holes in the ground that provide cover and concealment for individual troops. They range from simple one-man fighting positions to larger three or four man fighting positions, which usually operate a crew served weapon. If the foxholes are going to be used for any length of time, they will be improved by adding grenade sumps, overhead cover, and camouflage.

2.3.3 Revetments

A revetment is a large, below ground area for vehicles. This can be a parking area for aircraft or refueling vehicles, or a fighting position for an armoured fighting vehicle (AFV) or self-propelled gun. If it is intended as a fighting position, it usually has a ramp up to a firing point, allowing the vehicle to shoot from behind a low wall of earth or concrete. When necessary, the vehicle backs down the ramp, dropping out of the enemy's line-of-sight. Revetments have an opening to the rear that allows the vehicle to leave easily, if a hasty advance or retreat is required. Permanent revetments always have overhead cover to park the vehicle, as protection from artillery impacts and aerial observation.

2.3.4 Bunkers

Also known as strong points, bunkers are the primary fortification for heavy weapons. They are constructed of combination

layers of armour, earth, concrete, or whatever else that will protect the occupants. The bulk of a bunker is below the ground level, making it difficult to estimate its actual size and armament. Tunnels or trenches may connect it to other bunkers or fighting positions. Bunkers are constructed with a primary field of fire and may have one or two secondary fields of fire to either side. Trenches will generally connect to the rear of the bunker, limiting its field of fire and observation in that direction. Tunnels or elevators will enter from below ground level, allowing a completely circular bunker or even a rotating weapons turret.

2.4 COUNTERMOBILITY DEVICES

2.4.1 Simple Obstacles

Anything that limits an enemy forces choices during manoeuvre is considered a countermobility device, commonly referred to as an obstacle. Vehicles equipped with antigrav (working against gravity: popping up) are not significantly slowed by most simple obstacles, although they may be used to force such a vehicle to pop-up as it passes over the obstacle. This allows an anti-vehicular weapon nearby to take a shot at it, possibly at a lesser-armoured area. Hedgehogs, log cribs, ditches, road craters, and stump rows are all examples of simple obstacles. Combined with mines, and covered by friendly fire, these simple obstacles can slow or stop an infantry advance as well as force vehicles to bypass the area.

2.4.2 Abatis

By felling trees with explosives or hand tools, an effective obstacle is created. The trees are felled on either side of a road or path, allowing them to fall across the road in overlapping rows. The trees should point diagonally across the road towards the direction of enemy advance, and should not be completely severed from their stumps. The trees should be cut nearly all the way through, about 1 m above the ground level. This makes removal of the obstacle very difficult. Anti-personnel mines and booby traps can be added to this

obstacle to increase its effectiveness. Felling of trees was a common solution in the past. From environmental considerations, its usage may be restricted in the future.

2.4.3 Mines

A wide variety of mines are available, from anti-personnel to anti-vehicular. They range in size from about the size of a golf ball to nearly ½ m across. They can be purposly built or improvised from other materials and explosives. These are the most effective obstacle but also require the utmost skill to deploy. Mines may be placed by hand, air-dropped, delivered by artillery or emplaced by a mine warfare vehicle. When used to enhance obstacles, mines are nearly always emplaced by hand. It must be borne in mind that mines are double-edged weapon and the use of anti-personnel mines in the future may be banned.

Representatives of more than 100 countries have ratified or signed the Ottawa Convention banning the use, stockpiling, production, and transfer of anti-personnel landmines (APLs). The accord entered into force from March 1, 1999, setting a four year deadline for destroying all APL stockpiles. Till early 2003, 88 signatories have fulfilled their stockpile destruction commitments. Another 22 are currently working towards their destruction commitments. Currently, 145 countries are parties or signatories to the accord, but some key countries have shied away, including the United States, Russia, China, India, Pakistan, and several countries in the Near East. Some of these countries would join the treaty in near fututre if they could identify and field suitable alternatives to its mines outlawed by the treaty. However, as on today, at least as far as the Indian subcontinent is concerned, no war will be fought without the recourse to the use of APL. However, India has always ensured that all the landmines used are properly accounted for and are neutralised as soon as the hostilities are over.

2.4.4 Concertina Coil

Spools of anti-personnel wire, either single molecule polymer strands, metallic ribbon, or the more common simple barbed line can be used as an obstacle to troop movement. These spools may be emplaced by hand, using a flitter or hopper, or strung out behind a

vehicle like a CET. They have almost no value as anti-vehicular obstacles but are greatly improved by the addition of mines.

2.5 OFFENSIVE OPERATIONS – MOBILITY

2.5.1 Bridging

Rivers, canals, streams, chasms, and ditches all pose a problem for friendly manoeuvre forces. To counter this problem, combat engineers have developed a number of techniques to bridge these obstacles. A hasty bridge can be constructed using inflatable bridging sections (called pontoons when used to bridge a water obstacle). These are filled with foam that hardens quickly, becoming rigid and capable of supporting vehicle traffic in less than an hour. Alternatively, an armoured bridge laying vehicle (ABLV) may be used to span the gap. The ABLV moves into the gap and extends its bridge span, allowing vehicle traffic in less than ten minutes. When the bridge is no longer needed, the ABLV retracts the span and rejoins the manoeuvre force.

2.5.2 Breaching Minefields

Minefields pose a serious threat to manoeuvre forces. Combat engineers have developed rapid and effective methods for breaching them. Depending on the tactical mission and the urgency of the situation, the combat engineers may use explosive devices like charged line mine clearance (CLMC), mine warfare vehicles or hand tools to clear a path through the minefield. As most minefields are covered by enemy fire, this operation can be even more hazardous than one might expect. This is the reason behind so many defensive countermeasures that were developed by the combat engineers to protect themselves while working (anti-laser aerosols, smokescreens, mineshoes, etc.).

2.5.3 Clearing Obstacles

Simple obstacles may restrict or halt the advance of friendly troops, requiring the combat engineers to deal with the obstacles rapidly. Nothing works better than the combat engineer tractor (CET), since it was designed with this purpose in mind. However, other methods exist and may be employed as the situation warrants.

Explosives, indirect fire, mechanical, and hand tools may be used to reduce or remove an obstacle.

2.6 OBSTACLE PLANNING

Commanders and staff consider the use of obstacles when planning offensive and defensive operations. During the decision making process, obstacle planning is incorporated to ensure obstacle integration effectiveness and that the obstacle plan is flexible enough to allow changes during the phases of the operation. Obstacle planning requires integrating information from the staff and includes following factors:

2.6.1 Intelligence

- Friend or Foe
- Enemy combat power
- Location of enemy forces (location and formation)
- Enemy objectives, main effort, and options
- Target areas of interest (TAI) and/or decision points (DPs)
- Enemy vulnerabilities and enemy DPs
- Enemy breaching capabilities
- Time in the battle zone that friendly and/or enemy forces will be active

2.6.2 Logistics

- Type and quantity of material available
- Location of the material
- Where the material is required
- Distance from current location to required location
- Availability of personnel
- Availability of construction equipment

2.6.3 Fire Support

- Total fire-support capability (such as batteries, battalions, attack helicopters, or fixed-wing sorties)
- Family of scatterable mines (FASCAM)
- Capable assets (artillery/air-delivered; priority of fires, and deployment authority)

2.6.4 Engineers

- Terrain analysis
- Enemy engineer mission and mobility and/or survivability capabilities
- Friendly mobility and/or survivability capabilities

2.7 PLANNING CONSIDERATIONS

To achieve the maximum effect from a barrier, obstacle, or minefield around existing terrain feature (e.g., mountain chain or a strait) or a manmade structure (e.g., air base, canal, highway, or bridge). Cover them with observation and fire. Fields not covered by observation and fire are rarely effective. Analyse the ability of friendly and enemy forces to manoeuvre on land and sea or to conduct effective air operations.

2.7.1 Offensive Considerations

- Enhancing and protecting the friendly force's ability to manoeuvre
- Preventing enemy reinforcement or counterattack
- Facilitating economy of force
- Providing security
- Degrading enemy air and naval capabilities
- Fixating on the enemy

2.7.2 Defensive Considerations

- Directing toward degrading the enemy's ability to manoeuvre.
- Integrating systems of barriers, obstacles, minefields, and fires.
- Identifying reinforcing obstacles and minefields early.
- Identifying assets to restore the integrity of a barrier, obstacle, or minefield if breached by the enemy.
- Creating massive obstacles during land operations.

2.8 OBSTACLES

Obstacles are physical objects that impede the mobility of a force.

2.8.1 Obstacle Categories

2.8.1.1 Existing Obstacles

Existing obstacles are obstacles that are present on the battlefield as inherent aspects of the terrain. The two types of existing obstacles are natural and cultural. Natural obstacles are terrain features, such as rivers, forests, or mountains. Cultural obstacles are

manmade terrain features, such as towns, canals, railroad embankments, or buildings.

2.8.1.2 Reinforcing Obstacles

Reinforcing obstacles are obstacles specifically constructed, emplaced, or detonated by military forces. The categories of reinforcing obstacles are:

(a) **Tactical**: The primary purposes of tactical obstacles are to restrict enemy manoeuvre and multiply the effects and capabilities of fire power.
(b) **Protective**: Hasty or temporary obstacles created next to battle positions to protect defending forces.
(c) **Deliberate**: Permanent obstacles created at strong points or fixed sites.
(d) **Phony obstacles**: Units may also use phony obstacles that give the appearance of actual obstacles but require only minimal resources to emplace.

2.8.2 Obstacle Effect

Tactical obstacles and fires manipulate the enemy in a way that supports the commander's intent and scheme of manoeuvre. The intended effect that the commander wants the obstacles and fires to have on the enemy is called the obstacle effect. The salient features of obstacle effect are:

- Drive integration
- Focus subordinates fire power
- Focus obstacle effort
- Multiply the effects of fire power

Obstacle effect occur because of fire and obstacles, not just obstacles alone. All tactical obstacles produce one of the following obstacle effects (Fig. 2.1)

(a) **Disrupt**: Focuses fire planning and obstacle effort to cause the enemy to break up formation and tempo, interrupt timetable, commit breaching assets prematurely, and piecemeal the attack.
(b) **Turn**: Integrates fire planning and obstacle effort to divert an enemy formation.
(c) **Fix**: Focuses fire planning and obstacle effort to slow an attacker within a specified area, normally an engagement area.

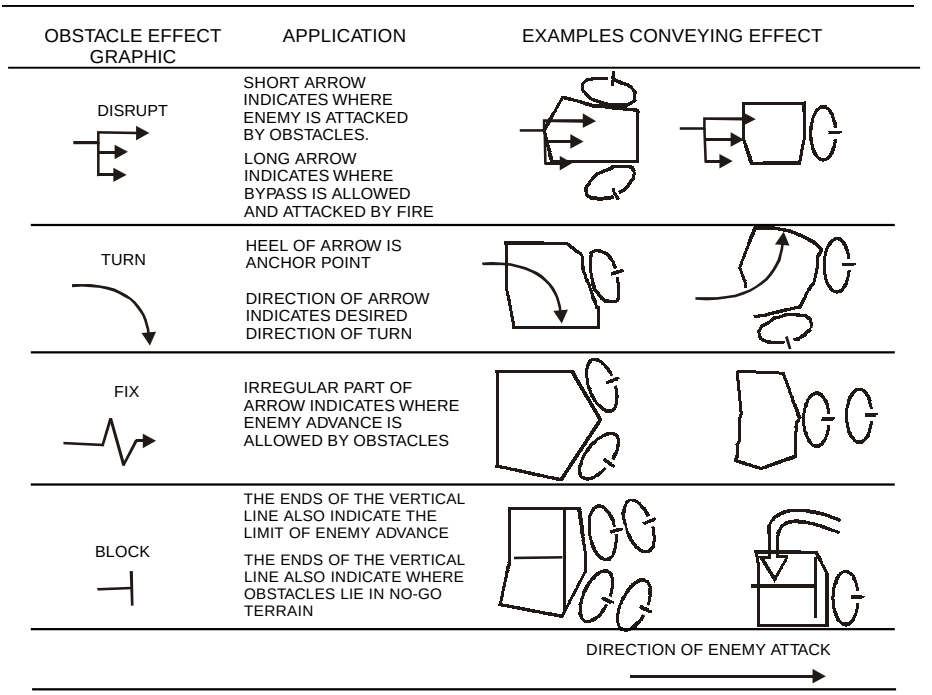

Figure 2.1. Obstacle intent and effect.

(d) **Block:** Integrates fire planning and obstacle effort to stop an attacker along a specific AA or prevent him from passing through an engagement area.

2.8.3 Obstacle Control Measures

Obstacle control measures are used to ensure that subordinates emplace obstacles that support the higher commander's scheme of manoeuvre and do not interfere with future operations. Obstacle control measures are groups, belts, and zones (Fig. 2.2).

2.8.3.1 Obstacle Groups

Obstacle groups are two or more obstacles grouped to provide a specific obstacle effect. For example, three obstacles are planned to turn the enemy into the battalion's area of operation (AO). While each obstacle could have a different effect such as fix, turn, disrupt, or block, the overall effect would turn the enemy into a kill zone.

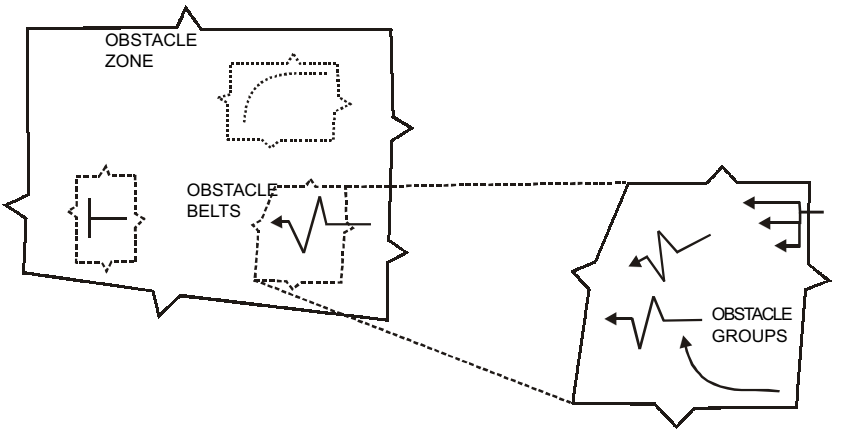

Figure 2.2. Obstacle groups, belts, and zones.

2.8.3.2 *Obstacle Belts*

Obstacle belts are a collection of obstacle groups that provide a specific effect. In the same way that obstacle groups use individual obstacles to achieve a desired effect, here, a series of groups are used to disrupt, turn, fix, or block the enemy on a larger scale. Belts are also a control measure for the regimental commanders to constrain tactical obstacle employment. They plan obstacle belts within assigned AO to grant obstacle emplacement authority to their major subordinate units to achieve a specific effect and/or outcome. Obstacle belts also focus obstacles in support of the regiment's scheme of manoeuvre and ensure that obstacles do not interfere with the manoeuvre plan of higher headquarters.

2.8.3.3 *Obstacle Zones*

Obstacle zones are used in the infantry division plan and are composed of a group of obstacle belts. Divisions plan obstacle zones based on regimental AO and ensure they do not impede future operations.

2.8.4 Situational Obstacles

Situational obstacles are obstacles that units plan and possibly prepare before starting an operation. However, these are not executed unless specific criteria are met. The commander can use situational obstacles to attack an enemy vulnerability, exploit success, separate follow-on enemy forces, or provide flank protection. Unlike directed

or reserve obstacles, a situational obstacle may be executed. Normally, units plan several situational obstacles that rely on the same assets for emplacement. This allows the commander to shift scarce assets to the location where he needs them the most. When planning, preparing, and executing situational obstacles, Commanders and staffs

(a) Identify the need and prioritise
(b) Plan for appropriate resources
(c) Integrate the obstacle with friendly fires
(d) Plan the obstacle
(e) Identify obstacle execution triggers
(f) Withhold execution of the obstacle until it is needed.

2.8.5 Conventional Mine Categories

Standard land mines consist of a small amount of high explosives contained in a metallic or nonmetallic casing, fitted with a fuse and/or a firing device for actuation by enemy vehicles or personnel.

2.8.5.1 Anti-personnel Mines

Anti-personnel mines consist of a small amount of high explosives in a container, fitted with a detonating fuze arranged for actuation by pressure, release of pressure by pulling on a tripwire, or release of tension.

2.8.5.2 Anti-tank Mines

Anti-tank mines consist of a charge of high explosives in a metallic or nonmetallic case. Anti-tank mines require a pressure of 130 – 220 kg to actuate a detonation. There are a variety of anti-tank mine fuzing systems (e.g., pressure, tilt-rod assembly, magnetic influence).

2.9 CROSSING MEANS

Crossing means is the equipment used to carry a force across water obstacle. This equipment is specially designed to operate within certain limits, and commanders must understand these limits if the force is to cross safely. A safety matter that affects operational use is the load capacity of rafts, bridges, and equipment. In exceptional circumstances, certain safety factors or margins allow an increase in the load. These

capacities have been deliberately omitted here because they are not intended for use in operational planning. The standard or design capabilities are provided for normal crossings. The exceptional category is intended for special situations using the terms caution or risk crossings. In addition to the command decision required to employ caution and risk crossing loads, commanders must consider the physical status of the equipment.

Thus, crossing force commanders obtain a professional judgment from an engineer. The commander weighs these factors with the tactical needs before directing an increase in the load, keeping in mind that the equipment may be lost for future use. River-crossings have three categories:

- Normal crossing
- Caution crossing
- Risk crossing.

2.9.1 Description of Crossing Means

The crossing means discussed above is an important element of any operational planning for an obstacle-crossing. The meticulous planning of the crossing means is very crucial for the success of any operation. During peacetime, considerable training is imparted to the bridging party and various tactical situations are analysed and experimented. Ultimately, it is the type of obstacle, the capability of the equipment bridge and the dynamic battlefield conditions that will influence the outcome. Therefore, the equipment capability tables, resource plans and the construction drill is to be well documented and rehearsed so that the risk element is greatly reduced. Each army, therefore, brings out its own manuals and handbooks to suit its organisational needs. The Indian army being a major and innovative user of different types of crossing means, works out its own system for every equipment in all possible obstacle-crossing situations. This is done after considerable studies and training is carried out at the centres, bridging training camps, and during exercises. It is however not possible to document any of these procedures in this Monograph. However, the meticulous way in which the American Military Systems documents

are prepared is worth emulating. The US Army Field Manuals are generally available on the Internet as open source documents.

2.10 COMBAT ENGINEERING IN THE INDIAN SUBCONTINENT

India after its independence has fought wars with neighbouring countries on several occasions. The prominent amongst these were 1962 Indo-China war, 1965 Indo-Pak war, and 1971 Bangladesh liberation war which was fought on both eastern and western borders. The last one of these is sometimes called as the engineers war since considerable engineering effort was involved in crossing major rivers and obstacles on the eastern front and defensive cum offensive posture was to be maintained on the western front. While the river-crossing on the eastern front could be well managed with the World War II vintage equipment like the good old Bailey bridge and its variants, on the western front crossing of canals and rivers posed a major challenge. It is true that in 1965, the Ichhogil canal could be crossed by the Indian army with the same old equipment, but it was not that simple in the years to come. The obstacles themselves had become more formidable over the years mostly due to the fact that both sides were continuously engaged in creating more difficult obstacles through a network of canals and DCBs. The upstream control of the water level in the irrigation canals and inundating nearby areas was also a common technique used by both sides to create situational obstacles over the entire stretch of the border. Over the last half a century, the plains of Punjab and Rajasthan have been converted into unnatural features such as ditches and bunds over hundreds of kilometres along the border.

The terrain of the India-Pak border is a mix of geographic extremes. From the high peaks of the Great Himalayan Range in the north to the vast salt flats of the Rann of Kutch in the south, the terrain along the border shows great variation in elevation, relief, and surface cover. Most of the India-Pak border terrain is not conducive to large-scale, combined military operations. The extensive stretches of sand dunes in the Great Indian Desert and the high-altitude glaciers of the

Himalayas, although quite different in nature, present equally severe logistical and operational constraints on military forces.

Those regions of the border area that contain the most trafficable terrain are generally found between Jhelum on the north and Ganganagar, where widespread areas of flat, sparsely vegetated terrain are found. This particular area of the border is bound on the north by the mountains of Jammu and Kashmir, and on the south by the northern reaches of the Great Indian Desert. It includes terrain where the Indians and Pakistanis committed considerable forces in the fierce battles of the September 1965 and December 1971 Indo-Pak wars. Numerous strategic points are found in proximity to the border in this area. These include the Pakistani city of Lahore, Pakistani lines of communication to Rawalpindi and Islamabad, and Indian lines of communication to Jammu and Kashmir that has been a constant source of tension between the two countries since 1947. From the information available from various sources on the 1965 and 1971 Indo-Pak wars indicate that the area contains strong fortifications built by both countries to enhance the limited protection of the relatively open terrain. Should hostilities erupt in the future, conduct of military operations at many points along the Indian-Pakistani border is going to be the natural consequence. The natural and man-made obstacles on both sides of the border will not stop either side from launching an offensive to cross the obstacle despite strong fortifications and minefields. Thus, the bridging equipment that is most relevant is the one that will provide satisfactory solutions to such difficult problems. Therefore, rather than the performance characteristics of the bridging equipment alone, what is more important is the efficiency of the obstacle-crossing .

The most important man-made obstacles are the canal systems that cut across the supra-region generally from north to south. These are hindrances to an attacker and are easily breached only at existing bridges, of which there are many. Observation throughout the supra-region is good, and fields of fire are excellent. The only exception to these conditions will be in and around the urban areas where fields of fire and observation inward will be degraded by the density of the structures. Conversely, cover and concealment throughout the supra-

region is poor, except as can be achieved in urban areas, or behind/ beneath man-made structures. The roadways along the canals, for example, will offer some concealment, and will facilitate the construction of cover. In the September 1965 Indo-Pak war, the Indian army launched several secondary attacks in the supra-region aimed at breaching the Ichhogil canal defensive line (Marala Ravi link) and the communications centre at Sialkot. Pakistani counter attacks and the lack of decisive preponderance in combat power on either side led to a stalemate in which both sides achieved only limited territorial and operational gains. The terrain in this supra-region, including natural and man-made obstacles, will not favour the defender unless fortifications are prepared in depth. The most positive factor for an attacker with a sufficient combat power advantage is the element of surprise, which will degrade about three days after the initial shock wears off the defender. The following table illustrates advance rate possibilities.

	Attacker	**Defender**
Best case	Advance rate 20 km per day	Advance rate 30 km per day
Worst case	Advance rate 5 km per day	Advance rate 18 km per day

2.11 CONCLUSION

This chapter introduces reader to the various obstacles and their crossing means. Since the aims of the two adversaries are diametrically opposite, it is not a simple game. The basic issues of the element of surprise, equipment design, planning and technology are as important as the aspects of continuous training and improvement. The discipline that is enshrined in any military operation is well imbibed in the obstacle planning and crossing operation involving military bridging equipment or the crossing means is available on Internet as open source document and one can further advance his knowledge by referring to that.

CHAPTER 3

TYPES OF MILITARY BRIDGES

3.1 BACKGROUND

The purpose of military bridging equipment is to get troops and equipment across the obstacles under battlefield conditions and during peacetime. The equipment bridges are meant to keep the trunk and important routes open even when the enemy attempts to destroy the civilian infrastructure. As a consequence, the equipment bridges have to negotiate different types of obstacles. The main classification of the military bridges, therefore, depends upon the type of obstacle the bridge can negotiate as well as the operational situation (such as assault crossing or replacement bridge) under which it is put to use.

This chapter would therefore emphasise the basic features that any standard equipment bridge must have. Some deliberation on the type of obstacle to be negotiated and the most suitable bridge configuration for achieving this objective therefore would not be out of place. The fact that the World War II which resulted in many innovative and widespread applications of military bridging shows that the technological advances have greatly improved the performances of military bridges, adding a new dimension to the modern combat warfare. It would not be an exaggeration to say that the tactical mobility of an armoured column not only depends upon the tank design, but is also determined by the obstacle-crossing abilities provided by the bridging equipment. So much so that in certain operations, the latter may assume much more importance than the individual mobility of the tank.

In India, and in many other developing countries, the British system of military planning has been followed as a matter of course. The Experimental Bridging Company (EBC), Royal Engineers has provided the role model to the Indian Army Engineers for over two centuries. It may therefore be worthwhile to have a brief overview of this pioneering and historic unit of the Royal Engineers.

3.2 THE PIONEERS

Temporary bridging had always been one of the roles of the Royal Engineers. The engineers had held bridging camps at Bure near Christchurch, UK, before World War I and continued to do so afterwards during the 1920s. The coming of the tank and other mechanised transport meant that the temporary bridges would have to support much heavier loads. Three special Bridging Battalions of Royal Engineers were formed at Christchurch in October 1918 to develop the idea of bridge launching tank. The EBC was formally set up at Christchurch on 28 February 1919. The author had the opportunity to receive training in military bridging at Christchurch in 1974.

During the World War II, the famous Bailey bridge emerged as a dramatic solution to the requirement of ground forces for a tactical or an assault bridge. Going by the firepower available with the enemy, the construction timings of a few hours and the construction party equivalent to a company was perfectly acceptable. The most important features of this bridging system were flexibility and modularity which make it handy for the universal use. The pioneering work in the field of military bridging, right from the early 20th century, was carried out in the UK by the Military Engineering Experimental Establishment (MEXE), later designated as Military Vehicles and Engineering Experimental Establishment (MVEE). During the last one decade, UK's Ministry of Defense has undergone a major organisational chnage. The MVEE has disappeared from the scene and now industries are directly participating in the equipment development. The Defence Evaluation & Research Agency (DERA) oversees the operations and planning. DERA separated into the following two organisations from 2 July 2001.

(a) Qineti9 – A Science and Technology Company
(b) DSTL – Defence Science and Technology Laboratory - an agency of UK, Ministry of Defence.

In August 1925, the name of the unit was changed to the Experimental Bridging Establishment (EBE) and throughout World War II it was known as EBE and had a military commander, a workshop staffed by civilians, and one designer (Mr Donald C Bailey later Sir Donald). Between 1926 and 1939, the staffing level of EBE fell to one Royal Engineers officer, one civilian designer, one draughtsman, and a 14-men workshop. The war office even questioned the retention of the sole designer Mr DC Bailey.

Between the two World Wars, EBE developed a number of bridges to cope up with the increasing weights of new tank designs. These included:

(a) An improved version of the Inglis Bridge, used in World War I
(b) The large box girder bridge named after Martel, the First Commander of the EBC
(c) The small box girder bridge
(d) The Hamilton Bridge
(e) The new floating bridge

With the onset of World War II, EBE expanded the work on these bridges. The current in-service tank was the Maltilda tank weighing about 26 tons. This stretched existing bridges to their limits and the next tank was the Churchill tank that was going to be much heavier.

In December 1940, EBE received approval to construct a pilot model of a bridge using a new design. Its manufacture involved the welding of high tensile steel, a novel process in 1940. EBE's designer, Mr Donald C Bailey had proposed the idea of a bridge made of flat panels before the war but the proposal had been shelved for economic reasons. The permission to proceed initiated 12 months of hectic activity. Design began in December 1940, the pilot model was ready

for testing in 1941 and the first production bridges were in-service by December 1941 just before the arrival of the Churchill tank. Over 600 firms were involved in the production of the bridge. During the last three years of the war, some 500,000 tons were manufactured, representing over 200 miles of bridge.

Field Marshal Montgomery wrote in a letter about the Bailey bridging as: "*Bailey bridging made an immense contribution towards final victory in World War II. As far as my own operations were concerned with the Eighth Army in Italy and with the 21st Army in NW Europe, I could never have maintained the speed and tempo of forward movement without large supplies of Bailey bridging*".

Thus, by the time the World War II came to an end, a lot of water had flown under these new bridges, giving confidence to the operational planners to establish proper relation between various types of obstacles and the equipment bridges that were available to them for deployment. It may be worthwhile, therefore to have a quick review on the types of obstacles and the methods available to the engineers to negotiate them.

3.3 METHODS OF CROSSING OBSTACLES

The methods of getting men, material, and vehicles across water obstacles can be broadly divided as follows:

(a) Fords
(b) Ferries
(c) Bridges

Since this monograph is primarily dealing with bridges only, a brief description will be given on first two items, while the types of bridges and their design aspects will be covered in detail.

3.3.1 Fords

Though an obvious method, fording is apt to be overlooked. It has the advantage of speed and simplicity, but clearly suffers from some severe restrictions. Fords are usually found in rivers that have seasonal variation in water levels. This is most common in Indian rivers that

depend upon water draining from the monsoon catchment areas. There are local fording sites which have been in traditional use by the local inhabitants. Many such sites might have fallen in disuse. Keeping a database of such sites can help a military engineer to plan a crossing operation using fording equipment in certain seasons. This gives an advantage, since the potential crossing points can now be multiplied bringing pressure on the enemy defences.

The allowable fordable depths depend upon the vehicle design as well as the water currents. When there are no specifications available, the permissible fordable depths can be assumed as

Motorcycles	0.3 m
Cars and light trucks	0.4 m
Trucks	1.0 m
Tanks	1.2 m

The above figures are to be used only when detailed specification of the vehicle is not available. Understanding the importance of fording capability, the modern military vehicle designs give due importance to fording capability. It is common to find fording capability of 1.5 m built in the design of modern wheeled and tracked vehicles.

The other major parameter crucial to fording is the river bed condition. When the soil is slushy and of poor grade, the vehicles that attempt fording will get bogged down. The interesting part is that the vehicles may be able to make a few passes, but with each pass, the soil will degrade and thus may lock up a number of vehicles on both sides of the river bank. To solve this problem, equipments such as fording mats can provide satisfactory solution. Such equipments can be mechanically laid, anchored, retrieved and reused. The Indian equipment, Fording Mat MLC 70 is a good example of this. Figure 3.1 gives a photograph of this equipment.

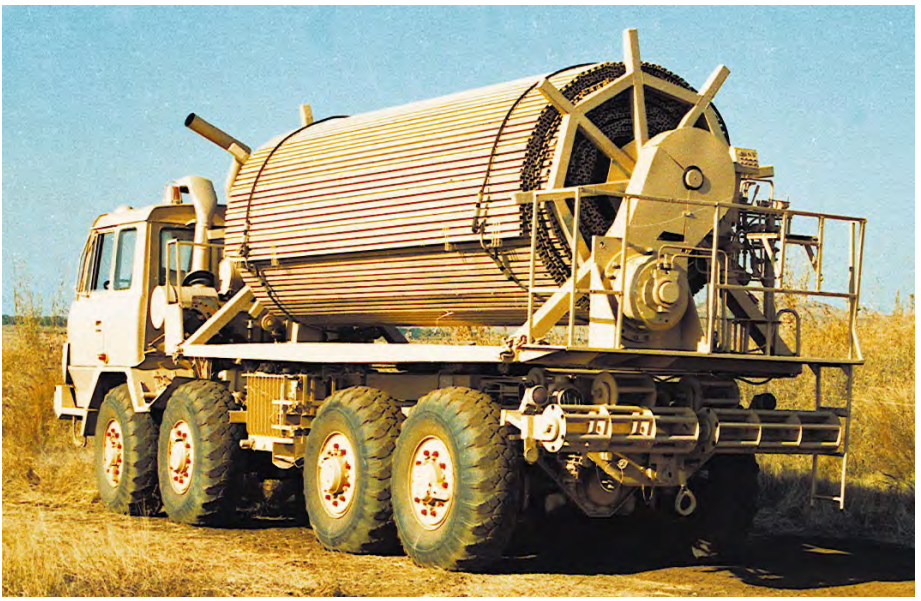

Figure 3.1. Fording mat MLC 70.

3.3.2 Ferries

Boats, both power-driven or rowed, are most suitable means for initial infantry crossings. Their limitations are that they cannot carry anything heavier than recoilless guns and light vehicles even if two boats are coupled together. Amphibian vehicles, which were successfully developed and deployed in good numbers during the World War II, have great advantage in that, they can cross the obstacle at any point of their choice. The limitations being the slopes and ground conditions at the entry and the exit.

Whatever boats and amphibians cannot cross, ferries can provide a satisfactory solution. While floating bridges are the real solutions to river-crossing problems, rafts and ferries can provide a good temporary solution. Moreover, if the floating bridges are to be used only during dark, these can be broken up in ferries and rafts for use during day. In most cases, the field commander will make an optimum choice of using a right combination of rafts, ferries, and floating bridges. Figures 3.2 to 3.4 show pictorial views of these.

The canal and river can pose major problems of approach for bridging vehicles. Trackways provide a good solution to these problems. Trackways are expedient for negotiating marginal terrain contiguous to bridge and ferry sites. They are ideally suited to provide mobility on loose desert sands. Figure 3.5 shows MLC 30 trackway developed for the Indian Army using aluminium alloy.

Figure 3.2. A pontoon raft.

Figure 3.3. An amphibian ferry.

Figure 3.4. Bailey pontoon bridge – still in use for river-crossing.

Figure 3.5.An MLC 30 trackway developed for the Indian Army using aluminium alloy.

To summarise, the use of ferries is influenced by the following factors:

(a) Ferries use very little equipment.
(b) Ferries provide a convenient way of getting vehicles back across the river in early stages when bridges are reserved for one-way forward traffic.
(c) Crossing places for ferries could be dispersed, thus well defended.
(d) Ferries present a difficult target for the enemy artillery or the air attack.
(e) Mobility is far better than equivalent equipment bridges.
(f) The manpower requirement for maintenance and continuous operation is heavy and much more than for bridging equipment.

3.3.3 Types of Military Bridges

Military bridges can be classified based upon their design, method of usage or actual deployment in combat. While the first two aspects are more technical in nature, the most important consideration from operational planning angle is the last one, i.e., classification from the end operational use angle. The examples of the first two types is deck type or through bridge and fixed/dry gap against wet gap/floating bridge. While this monograph will separately cover the aspects related to floating bridges, the main consideration decided by the operational parameters is discussed in detail.

3.4 ANCILLARY EQUIPMENT

Apart from the main obstacle-crossing equipment, any bridging operation would need other ancillary equipment related to reconnaissance, earth moving, mine laying and clearance, and some amphibious equipment to access the entire bridge marshalling harbour as well as the far bank and the water obstacle itself. Such equipments generally include the following:

(a) Amphibious reconnaissance equipment (Fig. 3.6)
(b) Combat engineer tractor (CET) or amphibious dozer (Fig. 3.7)
(c) Mine laying and marking equipment (Fig. 3.8)
(d) Mine detection and clearance equipment (Fig. 3.9)

Figure 3.6. An amphibious reconnaissance equipment.

Figure 3.7. A BMP-2 based amphibious dozer.

Figure 3.8. Linear motor operated minefield marking system.

Figure 3.9. Flail is capable of clearing mines buried up to a depth of 25 cm below the ground surface.

3.5 GENERAL CONSIDERATIONS

The aim of military bridging is maintaining the mobility of a force by opening and keeping the routes open across dry and wet gaps, and also giving solutions to crossings across dynamic obstacles such as craters, minefields and pipelines. In recent years, there has been a phenomenal increase in the firepower and precision, and in the initial phase of a war, the bridges become the first target. Not only civilian bridges are first targeted to disrupt the enemy's communications and supply routes, but also subsequent efforts to rebuild alternate bridges and continuous surveillance and monitoring is also done. If an assault operation is planned, it will invariably require obstacle-crossing solutions to keep the tactical mobility of the armoured column intact. During an advance, value of natural water obstacles for defence to the enemy is likely to be accentuated, resulting in increased importance of assault crossing operations in the modern ground war.

During World War II, especially in the Italian theater during 1944–45, extensive bridging operations were carried out using innovative methods and setting up new practices and technologies for large-scale bridging and amphibian operations. In the process, new developments such as Mulberry Harbours and amphibian vehicles like DUKW came on the scene producing technical surprise with dramatic effects. To cite an example, the Italian troops that were hiding in trenches, came out to see DUKW negotiating land or wayer obstacle with relative ease. As an outcome of this, several publications were released by the War Office, London, especially after the war was over. The US Army too initiated systematic studies on the mobility of wheeled and tracked vehicles, especially in the sandy terrains and waterlogged areas. The US Waterways Research Station was specially set up to address the issues emerged from the lessons learnt during the war. Although the pace of advance in modern warfare and other technological developments have made a major impact on the basic conditions, there are a few issues that remain unchanged.

Bridging is still primarily an engineer's task. In certain places, a new concept of Assault Engineer Regiments (AERs) with their own bridging equipment have been successfully developed. These AERs provide close support to the armoured columns and are therefore effective in maintaining pace with the column. Proper planning, training, and rehearsal in exercises are as crucial as the performance and design of the bridging equipment. It is also necessary that the plan is flexible so that in case anything goes wrong an alternative must be readily available.

The purpose of the tactical bridges associated with an assault operation – to strengthen the bridgehead. The construction of tactical bridges will almost certainly be liable to be interfered with ground action by enemy forces. Armoured assault bridges (AAB), a particular and most important form of tactical bridging, have the capability of spanning relatively small gaps (18–24 m) under fire. Therefore, these bridges must be constructed in minimum time, typically 5 to 10 min. These bridges preserve the impetus of the advance, which might otherwise suffer delays not proportional to the width of obstacle. Thus, the primary requirements of such bridging systems is to have the following:

(a) Minimum construction time (approx five min)
(b) Ability to be constructed under fire
(c) High degree of reliability
(d) Faster induction rate
(e) Ease of retrieval
(f) Mobility on par with the MBT

The disadvantages that are associated with such AABs are:

(a) These can carry only single lane traffic
(b) They have no permanent bridge seats (bearing), they are essentially temporary in nature.
(c) These are expensive and therefore not as easily available as some other forms of bridges.
(d) These have severe limitations wrt the types of gaps/obstacles.

3.6 MINES AND OBSTACLES

Due to the speed with which mounted operations progress in desert terrain, the use of mines to prevent surprise assumes considerable importance. Minefields are often the only obstacle placed in the path of the enemy due to the manpower and equipment demands of other obstacle options. Desert minefield emplacement involves large quantities of mines emplaced over vast areas. The lack of landmarks complicates recording the location and layout of minefields. The effect of wind on desert sand may result in shifting sand dunes or exposing or burying emplaced mines rendering them ineffective. Track patterns, unless carefully camouflaged, make minefield gaps and lanes easily detectable.

3.7 RIVER-CROSSING OPERATIONS

River crossings are second only to amphibious operations in complexity and vulnerability. A river-crossing operation is not specifically the same as a bridging operation, though there are many similarities. These similarities may vary only by the degree of the operational situation. Whether the crossing operation is hasty, deliberate, or retrograde, it requires advanced planning, training, coordination, and considerable equipment. Command and control, planning, unit relationships and responsibilities, and participation by various units are different with each type and size of crossing operation. Depending upon the nature of the river, soil conditions, water currents, and bank heights, each country tries to take maximum advantage of such parameters for defensive operations while carefully preparing plans for crossing the river at a few select locations where the conditions are favourable.

3.7.1 Hasty River-Crossing

A hasty river-crossing is a decentralised operation using organic, existing, or expedient crossing means. A hasty river-crossing is conducted by elements that have been suitably augmented with

crossing equipment and personnel well before anticipated crossing operations. It includes the rapid decentralised seizure of existing crossing sites and requires minimal concentration of forces with no loss of momentum.

3.7.2 Deliberate River-Crossing

A deliberate river-crossing is conducted when a hasty crossing is not feasible, when offensive operations begin at a river line, or when forced by a significant river obstacle. It requires detailed planning and centralised control with heavy reliance on crossing assets and personnel. Normally, a deliberate pause allows the concentration of combat power and additional bridging or rafting assets. It normally requires the clearance of the enemy from the entry side of the river and suppression of enemy forces on the exit shore.

3.7.3 Tactical Bridging

The tactical bridges, due to stringent demands for the performance and construction timings, have to depend upon the latest technologies and are thus somewhat expensive. This makes such bridges not readily available for use. Whenever such bridges are deployed, there is a pressure to release these bridges for use at more advanced positions, since the tactical mobility greatly depends upon the availability of such bridges. This brings in focus the need for replacement bridges or line-of-communication bridges.

3.8 CONCLUSION

In this chapter, an overview of different types of obstacle-crossing equipment and the general methods of classifying the same have been presented. This chapter also gives an account of the historical background of military bridging, which traditionally has originated from the Royal Engineers.

CHAPTER 4

DESIGN OF MILITARY BRIDGING EQUIPMENT

4.1 INTRODUCTION

The word design has different connotations when the military bridges – especially the equipment bridges are concerned. To a field engineer, it means correlating the assured strength/capability of an existing equipment to the requirements of the obstacle-crossing. The crossings are also typified separately since the battlefield scenarios are highly dynamic and keeping too much safety margin may be disastrous. Such designs put to use in the field are covered by handbooks or pocket books, which specify certain quick checks to select the equipment or to modify the same. In many cases such an approach leads to improvisations.

This chapter is written with two broad objectives. Firstly, it can help understand the capabilities of an existing military bridge to carry the standard or new loads. Secondly, if the bridging equipment is to be used in the normal civilian application areas, it can be ascertained by the user if it can withstand the expected loads that will be negotiating the bridge. From the above angles, in the succeeding paragraphs an attempt has been made to summarise certain design practices and guidelines that are generally followed across the major countries in the world. Therefore, this chapter can provide guidelines for designs of military bridging equipment as well as for verification of existing/new bridges to carry new types of vehicles that may

become relevant with the time. It should not be mistaken for a standard or a design code.

4.2 MILITARY BRIDGING – DESIGN CRITERIA

Before we take an overview of design guidelines, one point must be made clear. The design of a military bridge is really a tight-rope walk. One cannot be oversafe. Rather, the designer should specify at what load or under what condition his structure will have an assured failure. That is the criterion for a good design. In civilian bridges, an occasional overload must be tolerated. No catastrophic failure is acceptable as it can result in loss of human life and property. Also for civilian bridges, expectancy of life is much longer and periodical inspections should reveal damage, if any, so that damage control exercise could be undertaken. It may also happen that the usage conditions and parameters have changed over the years; yet the structure should be adaptable to these changes with minimum disturbance.

For a military bridge, the expectations are different. The bridge has to be transported and launched many times over. None of the systems or subsystems should get damaged during these operations. Most of the operations are carried out during night and under adverse weather and battlefield conditions. There is no scope to carry out detailed inspection during each launch or use. The bridge in other words, should be fault-tolerant. The bridge design should be optimum for the given conditions; and if any of the given parameters are exceeded, the failure will be acceptable to the Commander. There are different types of crossing operations, which have been explained in the earlier chapter. These take into account the risk, the caution, and the normal crossing. If the bridge design is overloaded with unnecessary additional safety factors, the overall performance will be degraded. To explain this point better, consider the effect of overdesign on the weight of the structure. It will be obviously more than the optimally designed bridge. This will amount to additional transport, additional manpower, and additional construction time.

Thus, the bridging system may lose its operational effectiveness or at least will be adversely affected. The military bridge design is normally proven at the prototype stage to not only assess its load-carrying capacity but to ensure that it fails under the predetermined excessive loads.

For a military bridge in operational use, there is an effective traffic control to ensure that there is no un-permissible load likely to pass over it. The parameters for deflections are generally higher than those for civilian bridges. But what differentiates it from its civilian counterpart is the fatigue life. The assault bridge spends more time in storage than in actual use. Also, it is launched many times over for exploitation/trials during exercises and for training. Thus, the launching components may have a life of about 1000 launches and 15 years in storage. Certain components like rubber seals, hydraulic, and pneumatic actuators have restrictions during storage life. The life could be extended by adopting total preventive maintenance and periodic overhauls.

As far as the usage of a typical assault bridge goes, it differs widely from the usage of civilian bridges. The military bridge, which is designed to carry the heaviest battletank will not be subjected to the peak loads for a large number of passes. Normally, 10,000 cycles of peak load indicates adequate service life for a military bridge. There are other types of smaller loads also negotiating the bridge; but predicting exact load spectrum is very difficult. Moreover, these loads being much less than the peak load, do not induce high level of stress in the bridge structure.

4.3 GUIDELINES FOR DESIGN

Further to the discussion on the design aspects of military bridges, the following guidelines can be seen in proper perspective. These guidelines are generally taken from the standards adopted by the NATO countries as the design aspects of military bridges. As brought out in chapter 8, during the hectic war periods, there was some confusion on the designation of bridge class numbers. It was thus somewhat difficult to work out if an existing bridging equipment

could withstand the loading coming from newly introduced battle tanks and wheeled vehicles. Adoption of a standard agreement Stanag 2021 on military load classification systems overcame this problem to a large extent. The next problem was the diversity of different types of military bridging equipment and different sources from which such equipment was coming. For example, the latest bridge on M1A1 tank of the US Army is a joint development between the USA and Germany. Similarly, many other variants of the German Leguan have been put on the platforms of other countries. If there was one design standard between the NATO countries, each country would not have to subject other equipment for elaborate trials, once the same is proved by one source under NATO. It may be wrong to presume that the countries outside NATO have no relevance to this. Especially in these times of globalisation, countries like India can keep an eye on the export market. If the Indian bridging equipment has to compete globally, conformity to such norms as listed (Appendix A) will carry more weight.

BROAD GUIDELINES FOR DESIGN OF MILITARY BRIDGES

(Source: Trilateral Design and Test Code for Military Bridging and Gap-crossing Equipment – amended May 2005)

A1 – GENERAL

A1.1 INTRODUCTION

A1.1.1 Bridging and gap-crossing equipment will be designed to meet the user's requirement by applying the necessary loading conditions, design parameters, and testing given in this code. The code lists material properties required and gives basic properties for materials generally used. The code also gives design data for guidance and checking, but the criteria are that the equipment pass the requisite tests, meet the user's requirement, and can be manufactured readily.

A1.1.2 Equipment designed and tested in one country in accordance with this code will be suitable for international acceptance, apart from user or troop trials.

A1.2 SCOPE AND FIELD OF APPLICATION

A1.2.1 This code covers loading, design, and testing requirements to be used, for the development of military clear-span bridges,

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piers, floating bridges, rafts, equipment causeways, and erecting and launching structures that are part of the equipment. The code is used to confirm that equipment will meet the performance specified by the user. The requirements of this code are to be regarded as the minimum acceptable standards of performance. Requirements for fibrous composite materials and adhesives are included but may not be complete.

A1.2.2 If different materials, unusual structures or techniques are used to which some portions of this code are inappropriate, the engineer is responsible for devising suitable but similar alternative provisions including the specifying and justifying of special tests.

A1.3 REFERENCES

A1.3.1 This code overrides all other national standards (except those listed below) relating to military bridging and gap-crossing equipment unless such standards are specifically called for by the user. The standards listed below as being valid in addition to the code should not be regarded as being complete. Additional unforeseen standards which may become relevant in the future should be agreed upon trilaterally.

A1.3.2 User's equipment requirement: Military Technical and Economy Requirement (Germany), General Staff Requirement (UK); and Operational Requirements Document (US).

A1.3.3 NATO Stanag 2021, computation of bridge, ferry, raft, and vehicle classifications.

A1.3.4 Qstags and Stanags for standardisation of equipment and detail.

A1.3.5 International Organisation for Standardisation (ISO) International Standards.

A1.3.6 American Society for Testing Materials (ASTM) or similar national standards.

A1.3.7 Production specifications.

A1.3.8 A list of standards related to paragraphs of this code is given in Appendix J – Standards (of Trilateral Design Code).

A1.3.9 DOT/FAA/AR-MMPDS-01, Metallic materials properties development and standardization*.

Note: MIL Handbook 5 withdrawn in 2004, replaced by DOT/FAA/AR-MMPDS-01.

A2 – DEFINITIONS AND SYMBOLS

A2.1 DEFINITIONS

A2.1.1 Allowable Stress

The maximum stress allowed caused by the design load *P*. The stress derived form the proof, yield, or ultimate stress divided by the appropriate safety factor.

A2.1.2 Applied Loads

The loads applied to a structure in addition to dead load *D*, or self-weight.

A2.1.3 Availability

A measure of the degree to which an item is in operable and committable state at the start of mission when the mission is called for at any unknown (random) time.

A2.1.4 Battlefield Day

See mission cycle.

A2.1.5 Bearing Contact (Hertz) Stress

The compressive stress due to pressure between elastic bodies.

A2.1.6 Buckling Stress

The stress due to the critical buckling load causing unsuitable equilibrium at which a member fails to perform its load-resisting function due to excessive deflection.

A2.1.7 Calculated Ultimate Load (U_c)

The design or working load, *P*, multiplied by the factor 1.5.

A2.1.8 Design Load (*P*)

The appropriate combination of loads that must be sustained by a structure without producing stresses in excess of the allowable/working value. For static test purposes it is the working load *P*. In the case of the ductile materials, not sensitive to stress concentrations, average stresses on net sections are satisfactory.

A2.1.9 Failure

Failure is when any structural or functional damage causes a member or structure to no longer perform as intended and prevents the completion of its mission; either launching, trafficking or recovery.

A2.1.10 Fatigue Design Life

The required life multiplied by a factor which varies according to the type of design adopted and a further factor if a mean stress/number of cycles (S/N) is used instead of the minimum curve.

A2.1.11 Fatigue Stress Range

The stress range to cause failure at the fatigue design life.

A2.1.12 Impact Factor

The factor applied to an induced static load to give the equivalent induced dynamic load caused by the load's movement.

A2.1.13 Maintainability

The ability of an item under stated conditions of use, to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels and using prescribed procedures and resources.

A2.1.14 Minimum Life

The life at a selected stress from an appropriate S/N curve at 97.5 per cent probability of survival.

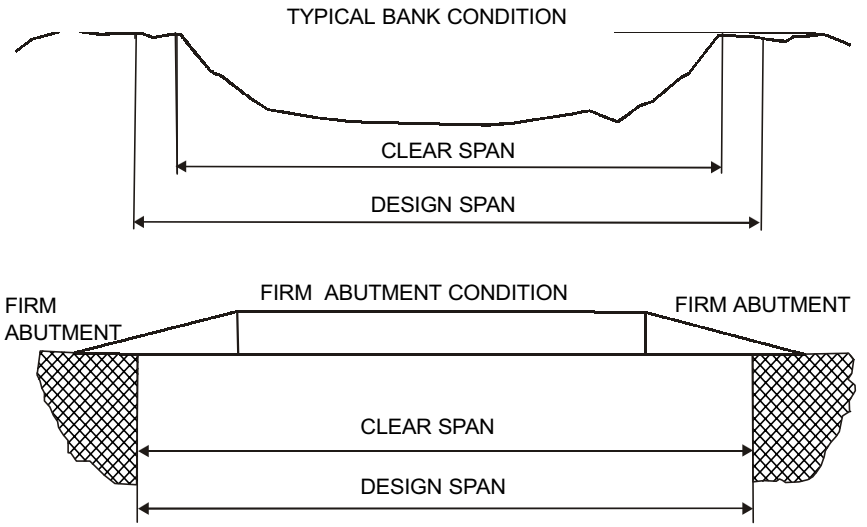


Figure 4.1. Typical bank condition.

A2.1.15 Mission Cycle

Includes road march, launch/erection of the equipment, vehicle trafficking and equipment use, and retrieval/ disassembly of the equipment.

A2.1.16 MLC

Military load classification

A2.1.17 Pin Bearing Stress

The compression stress normal to the axis of the fasteners (e.g., rivets, bolts, screws) on the projected area of the hole.

A2.1.18 Proof Stress

The stress at which a material deviates from the proportionality of stress to strain by a 0.2 per cent strain offset.

A2.1.19 Reliability

The probability that an item will perform to its intended function for a specified interval (mission) under stated conditions.

A2.1.20 Required Life

The fatigue life stated in the user's requirements.

A2.1.21 Rupture Stress

The same as ultimate stress.

A2.1.22 Shear Stress

The stress component tangential to the plane in which the forces act.

A2.1.23 Slope

Vertical rise or fall over the horizontal distance, usually expressed as a ratio (1 in 10).

A2.1.24 Span

The design span is the distance between the reaction points of the bank seats at each support of the bridge. The clear span is the gap to bridged as shown in Fig. 4.1.

A2.1.25 Stress Ratio

Stress ratio defined as equal to the maximum stress divided by the minimum stress.

A2.1.26 Test Overload (*O*)

The design or working load *P*, multiplied by the factor 1.33.

A2.1.27 Test Ultimate Load (*U*)

The maximum test load achieved by the bridge structure or component before sudden failure or instability.

A2.1.28 Ultimate Stress

The maximum tensile, compressive or shear stress a material is capable of sustaining.

A2.1.29 Working Load (*P*)

The same as design load, *P*.

A2.1.30 Working Stress

The stress caused by the working load *P*. The working stress may exceed the allowable stress.

A2.1.31 Yield Stress

The stress at which a material deviates from the proportionality of stress gain. This deviation may be expressed as a 0.2 per cent strain offset.

A2.2 SYMBOLS

The following symbols are used in this code:

A_i – Applied load to structure or component numbered in order of severity, with A_1 being the most severe

B – Braking load from vehicle (s)

D – Self-weight or dead load including impact during launching

F – Foot walk loading

K_C – Fracture toughness property for material (under plane stress)

K_{IC} – Critical stress intensity for cracking (under plane strain)

K_{th} – Threshold stress intensity

M – Mud load

N – Number of cycles to failure

O – Overload

P – Design load or working load

P_C – Stability design of floating bridge or raft components

P_{FAT} – Fatigue design load range

P_{TEST} – Applied test load related to actual material properties

Q – Hydrodynamic load: the resultant of horizontal drag or propulsion and vertical drawdown components

R – Function of.

S – Snow or ice load

T_1, *etc*– Strength parameters determined by test

U – Ultimate load

U_C – Calculated ultimate load

U_s – Minimum in-plane shear strength

V – Vehicle load, including appropriate impact and eccentricity

W – Wind load at appropriate velocity

W_p – Wind pressure at appropriate velocity

X_C – Minimum compressive failure strength of the unidirectional layer parallel to fiber direction

X_T – Minimum tensile failure strength of the unidirectional layer parallel to fiber direction

Y_C – Minimum compressive failure strength of the unidirectional layer perpendicular to fiber direction

Y_T – Minimum tensile failure strength of the unidirectional layer perpendicular to fiber direction

σ_1 – Normal stress in fiber direction

σ_2 – Normal stress perpendicular to the fiber in the plane of lamina

σ_3 – In-plane shear stress

σ_s – Shear stress

σ_t – Tensile stress

σ_v – Maximum stress

σ_x – Stress in x direction

σ_y – Stress in y direction

h – Height difference between near and far banks

n – Required number of cycles/life

Pb – Tracked vehicle ground contact bearing pressure on hard surface

v – Velocity

σ – Standard deviation

Additional symbols are defined in applicable appendices.

A2.3 CONVERSION FACTORS

Conversion factors for SI, Metric, and English units are in Appendix B - Conversion Factors (of Trilateral Design Code).

A3 – MATERIALS

A3.1 GENERAL

This section gives the material data which should be available to the designer and is required for international standardisation. The data should be presented in the form used in Annexure AA – Metal Data Sheets(included), Appendix E - Composite Materials Data Form, and Appendix F-Adhesive Data Form (of Trilateral Design Code).

A3.2 MATERIAL LISTING

Appendix AA- Metal Data Sheets, is a list of metals with brief information to assist initial selection. These are not the only metals for consideration. Approximate properties for composites for preferred methods of fabrication are given in Appendix G (of Trilateral Design Code) – Typical basic properties of fiber-reinforced materials based on 60 per cent fiber volume fraction epoxy composites.

A3.3 PRELIMINARY WORKING STRESSES

If when a metal is first considered only the 0.2 per cent proof for yield strength is known, the following factors may be used to obtain other working stresses from the working tensile stress:

Compression without buckling = tension

Shear = 0.6 × tension

Bearing = 1.33 × tension.

A3.4 DATA REQUIRED FOR SELECTED MATERIALS

A3.4.1 General

Name and/or number of material with a brief statement of the primary characteristics and any patent or proprietary restrictions.

A3.4.2 Application

State what the material is used for and the particular properties that make it desirable.

A3.4.3 Physical Properties

Give density, melting range, and average coefficient of thermal expansion for -18°C to 65°C (0 to 150°F).

A3.4.4 Elastic Constants

Give at 20°C (68°F) the Modulus of Elasticity, in tension and compression, and Poisson's ratio. Orthotropic properties should be given to consider the effects of grain orientation. Variances of more than 5 per cent at 38°C (100°F) should be noted.

A3.4.5 Fabrication Recommendations

List any special recommendations for working with the material.

A3.4.6 Ballistic Damage

It should be shown that any material or construction is satisfactory wrt ballistic damage. An assessment may be made on the basis of impact tests, fracture toughness, notch tensile/ compression tests, drop tests, and field shooting trials followed by test loading.

A3.5 DATA REQUIRED FOR SELECTED METALS

A3.5.1 Physical Condition Designation

List and define all common heat-treatment designations.

A3.5.2 Chemical Composition

Give the maximum and minimum allowable percentage weight of alloying elements and the maximum allowable percentage by weight of containing elements.

A3.5.3 Mechanical Properties

Minimum properties will be given for the parent metal and if they are different, for welds, heat affected zones (HAZ), and if applicable, for differently worked forms. Parent metal properties will be given for the longitudinal direction, in the rolling or extrusion direction, and if they differ, for the long transverse and short transverse direction as well as for various

thickness. In general, ultimate strength, yield strength, and elongation are guaranteed; however, other mechanical properties must be established and are minimum properties which can be expected, but are not guaranteed.

A3.5.3.1 Tensile

Give the 0.2 per cent proof strength, or yield strength, for a 0.2 per cent offset and the ultimate strength. Give per cent elongation in the longitudinal (rolling or extruding) direction with a 50 mm (1.97 inch) gage length. Testing should be in accordance with ISO/R82, R86, and R375 EN 10002 PT 5*, ASTM E8 BS 18.

A3.5.3.2 Compression

Give the 0.2 per cent proof strength, or yield strength, and the ultimate strength. Testing should be in accordance with ASTM E9.

A3.5.3.3 Bearing

Give the 2 per cent offset bearing strength. Testing should be in accordance with ASTM E238.

A3.5.3.4 Shear

Give the shear strength. Testing should be in accordance with ASTM B565.

A3.5.4 Fatigue Properties

Desirably give minimum stress/number of cycles (*S/N*) curves between 10^3 and 10^6 cycles with a 97.5 per cent probability of survival on a log-normal distribution for stress rations 0, + 0.5, -1 for the following specimens as required.

Smooth base material
Notched base material
Butt welds
Fillet welds
Connections other than welds.

* DIN 50-145 withdrawn in 191, replaced by EN 10002 PT 5.

A3.5.5 Fracture Data

Compare with other alloys and give the parameters K_C and K_{IC} details of the test specimen. Testing for K_{IC} should be to ASTM E399. Threshold stress intensity K_{th} and crack propagation data based on the fracture mechanics should be available for base material and welds/HAZ's.

A3.5.6 Corrosion Resistance

Briefly compare corrosion resistance with that of other alloys of the same material. Special corrosion characteristics including the effects of heat treatment, welding, and aging should be mentioned if they differ greatly from similar alloys.

A3.5.7 Stress Corrosion

Briefly compare with other similar alloys. Give the threshold stress below which stress-corrosion cracks do not initiate for smooth specimens, preferably in four-point bending, stating the time, environment, material, grain structure, and specimen orientation.

A3.5.8 Heat Treatment

Give details of any heat-treatment process pertaining to the material. Appendix D (of Trilateral Design Code), International Temper Equivalents for Aluminium Alloys summarizes heat treatment equivalents for three member countries.

A3.5.9 Welding and Joining

Give recommended welding electrodes and any special joint preparation requirements.

A3.5.10 Brittle Fracture

It should be shown that the material, as used in the structure, will not be subject to brittle fracture at the required low temperature by quoting nationally accepted tests or the transition temperature if applicable.

A3.6 DATA REQUIRED FOR SELECTED COMPOSITES

A3.6.1 General

This section includes glass, aramid, and carbon composites. It considers only the properties of the most commonly used cured composite for preferred methods of manufacture and adhesives. Individual properties of fibers and resin matrix should be entered on the data sheet shown in Appendix E—Composite Materials Data Form (of Trilateral Design Code), if available. Although these properties determine composite characteristics, they are no more than a guide to the expected composite material property levels. Physical and mechanical property data should be measured at 23 ± 2 °C (73 ± 4 °F) and 50 ± 5 per cent relative humidity (RH). Mechanical property data should also be measured at temperature and humidity conditions representative of severe operation, 50 ± 2 °C (122 ± 4 °F) 85± 5 per cent RH, or a higher or lower (Stanag 2831 withdrawn) condition, if specified. Preconditioning is required to achieve the equilibrium humidity content and temperature consistent with the test temperature and moisture (see ASTM D618 on preconditioning)

A3.6.2 Composite Description

Sufficient detail should be specified to define the composite constituents uniquely either in terms of manufacturers' coding or to accepted specifications. Lay up geometry, number of plies, volume fraction, and final thickness of the composite should be given.

A3.6.3 Processing

The method of producing the cured composite should be stated with details of curing times, pressures, and temperature cycles.

A3.6.4 Physical Properties

A3.6.4.1 The density, fiber volume fraction, and void content should be stated and determined in accordance with appropriate published standards. Calibrated alternative methods are accepted.

A3.6.4.2 Thermal expansion coefficient related to the operating temperature range should be given.

A3.6.4.3 Equilibrium moisture content and relative linear dimensional changes should be determined for the most severe operating conditions (temperature and humidity). This information should be used to specify preconditioning for test specimens. The glass transition temperature for the composite should also be given.

A3.6.5 Basic Lamina Mechanical Properties

The level of mechanical properties depends upon the strain rate and the physical state of the material in respect to temperature and moisture content. Properties for design should include measurement at the minimum median and maximum operating temperatures and show changes associated with moisture pick up. Preconditioning test conditions should be as specified in section

A3.6.5.1 Property data should be provided for individual lamina and for the (laminated) composite. The required lamina properties are identified in Appendix E—Composite Materials Data Form (of Trilateral Design Code), and include tensile and compression strength parallel and orthogonal to the fiber direction and in plane shear strength (see ASTM D3039, D3410, and D3518). Minimum guaranteed fiber strain must also be reported. Interlaminar shear strength (or transverse shear strengths for other than laminated composites) should be measured by procedure to be agreed upon.

A3.6.5.2 In addition, longitudinal, transverse, and shear moduli and Poisson's ratio should be obtained for the individual lamina. Longitudinal tensile, compression, flexural strength, and Poisson's ratios should be obtained on full thickness (laminated) composite coupons with the stacking sequences be utilised in production at severe operating conditions only as specified in section A3.6.1. Geometric discontinuities should be considered.

The mean value and standard deviation of each property should be determined from minimum sample size of 6.

A3.6.5.4 Application of any failure criteria to establish a composite strength analysis for multiaxial laminate in either a uniaxial or multiaxial stress requires a coherent set of basic ply properties as given Appendix E—Composite Materials Data Form (of Trilateral Design Code). Test methods to be based on appropriate published standards.

A3.6.6 Fatigue Properties

A3.6.6.1 Fatigue properties should be determined by test on appropriate specimens (ASTM D3039 provides specimen information). Test conditions should be designed to avoid build-up (ASTM D3479).

A3.6.6.2 A testing programme can be performed which provides minimum *S/N* curves between 10^3 and 10^6 cycles with 97.5 per cent probability of survival on a log normal distribution for stress ratios of 0, +0.5, -1.

A3.6.6.3 Alternatively, tests should be performed for the most severe operational stress envelope, i.e., between the minimum and maximum transient stress to which the component may be subjected, increased for a number of cycles equal to 1.8 times the design life.

A3.6.6.4 In either case, tests should be performed on full thickness specimens with the design stacking sequence for both smooth specimens and specimens containing geometric discontinuities (holes and/or notches) representative of design items.

A3.6.6.5 Correctly loaded components should be tested.

A3.6.7 Impact Susceptibility

Determine threshold of impact induced inter-laminar damage by drop weight tests, specification to be agreed upon.

A3.6.8 Stress Rupture/Creep

Determine to agreed specifications constant stress versus time curves for selected critical material stress cases. Creep behavior should be investigated at the maximum service temperature. The tensile specimen (ASTM D3039) is appropriate for both creep and stress rupture testing.

A3.7 DATA REQUIRED FOR SELECTED ADHESIVES

A3.7.1 General

This section relates to adhesives for structural composite bonded joints and metal attachments. The performance of adhesives can be significantly influenced by the prior preparation of the surfaces bonded. Guaranteed minimum strength properties must be established by testing representative joints. Typical data requirements are indicated in Appendix F—Adhesive Data Form (of Trilateral Design Code). Test conditions (temperature and humidity) and preconditioning should be as specified in Section A3.6.1 for composites. Correctly loaded joints should be tested.

A3.7.2 Adhesive System Description

Described by giving the manufacturer's coding and supplier and the form of adhesive used (liquid, paste, or film). The nature of adhesive should be giving intended application (adherends and service environments). The system components should be listed including compatible primer systems.

A3.7.3 Processing Requirements

Indicate surface preparation, assembly methods, and pressures and time/temperature cycles to obtain stated properties. Minimum curing temperatures to be given and range of allowable bond line thickness stated.

A3.7.4 Physical Properties of Cured Adhesive

A3.7.4.1 State the glass transition temperature.

A3.7.4.2 State the transverse electrical resistivity.

A3.7.5 Mechanical Properties

The level of mechanical properties may be affected by strain rate of testing and the physical condition of the bonded system. Mechanical property data should be developed at the conditions defined in Section A3.6.1. The following data should be reported: tensile and shear load, and peel strength;

tensile and shear moduli, elastic, and inelastic tensile and shear strain limits. Application of the data in Annexure AF – Adhesive Data Form, to selected joint configurations should take into account stress concentrations arising from geometrical factors and adhered stiffiness. Test methods should be in accordance with appropriate published standards, such as ASTM E229 (shear strength and modulus), ASTM D897(tensile strength), ASTM D1876 or D3167 (peel strength).

A3.7.6 Fatigue Properties

Fatigue properties of many adhesives are particularly sensitive to cycling rate and should be determined under conditions close to that of use under the most severe operating environment. The following fatigue tests should be performed: tension, shear, and peel. Either minimum S/N to failure curves should be developed or fatigue tests specific to the design load envelope should be carried out as specified in Section A3.6.6. Adhesive fatigue properties may be compared using standard test methods but allowance for geometrical stress concentration should be made on other joint geometries and testing of representative test coupons is essential.

A3.7.7 Environmental Degradation

A ranking of the expected durability of selected adhesive/ adhered surfaces should be given in terms of wedge test crack propagation or stressed lap shear test, but specific factors can be obtained only by testing representative joint details for details of surface preparation techniques should be given. The rate of environmental degradation will also depend on the specific geometry and stress system applied to the bonded joint.

A3.7.8 Creep Behaviour

To be based on ASTM D2294 or British Standards 3250 Part C7 with preference for a thick adhered single-lap shear specimen. Creep behaviour should be investigated at the maximum service temperature.

A4 – DESIGN PARAMETERS

A4.1 GENERAL

The design parameters below are to be used unless modified by the equipment/specification. Generally, the parameters represent the worst conditions achieved during normal service, and average usage should not be so severe. In some instances a desirable alternative parameter is given and it should be regarded as an improvement that the designer should try to achieve. The designer will have to balance cost and effect with the achievement of desirable parameters, and it may not be possible to achieve all parameters. Abnormal service parameters should be covered by special tests on the equipment. Parameters are given for clear span bridge, piers, floating bridges, and rafts.

A4.2 CLEAR-SPAN BRIDGE AND GENERAL PARAMETERS

A4.2.1 Minimum Clear Roadway Width

Military load class (MLC)	One-way (in m)	Two-lane (equal MLC) (in m)
4-12	2.75	5.50
13-30	3.35	5.50
31-70	4.00	7.30
71-100	4.50	8.20
Above 100	5.00	not allowed

A4.2.2 Truss Bridge Roadway Width

For through truss bridges with exterior curbs: Face of curb to inside of truss to be 250 mm (10 inch) minimum from 300 (12 inch) mm above the deck to the top of truss.

A4.2.3 Footwalk Width

Width will be minimum of 650 mm (2 ft, 2 inch).

A4.2.4 Trackway Width for MLC 31 and Above

Minimum width for single-track way will be 1.525 mm (5 ft). Maximum centre gap will be 950 mm (3 ft, 1 inch) (Dimensions must be checked to suit all vehicles expected to use the trackway).

A4.2.5 Bank Conditions

A4.2.5.1 For assault (close support) bridges, the height difference h, between home and far banks is essentially 1 in 10 (10 per cent) and desirably 1 in 5 (20 Per cent) multiplied by the length of the span up to a maximum of 6.0 m. For assault (close support) bridging, h, is measured from the home bank slope projection.

A4.2.5.2 For support {general support} bridges, the maximum height difference, *h*, between home and far banks is essentially 1 in 10 (10 per cent) multiplied by the length of the span up to a maximum of 3.0 m. for support {general support} bridges, *h*, is measured from the home bank horizontal projection.

A4.2.5.3 For safety purposes to prevent wheeled vehicles slipping sideways off the bridge, transverse deck slopes between any two points on the bridge deck surface under live load shall not exceed 1 in 10 (10%). This is known as the serviceability limit. In the case of twin trackway bridges with structural infill decking, this is considered part of the bridge deck surface.

A4.2.5.4 Consistent with the serviceability limit, it must be possible for bridges and the launching system to accept uniform transverse slopes*, or steps, bumps or depressions equivalent to a transverse slope, anywhere on the bankseat supports of the following gradients:

Assault {Close Support} Bridges (CSBs) 5.0% (1 in 20)

Support {General Support} Bridges (GSBs) 2.0% (1 in 50)

Line of Communication (LOC) Bridges 0.5% (1 in 200)

A4.2.5.5 For multi-span bridges (including combination bridges and bridges supported on a fixed or floating pier), the same conditions for transverse slopes or irregularities must be

*Note: It must also be considered that near and far banks can have like or opposing transverse slopes, i.e., +1 in 20 near bank, ±1 in 20 far bank.

considered to be applicable at the intermediate supports. For continuous floating bridges (e.g. Ribbon or M3) the same transverse bankseat criteria shall apply to the supporting ramps providing access and egress to the roadway.

A4.2.6 Bank Bearing Pressure

A4.2.6.1 Assault {Close Support} bridges shall be designed to bear uniformly on a projected length of 0.75m (2 ft, 6 in.) measured from the extreme ramp toe. Under such conditions maximum bearing pressures should not exceed 380 kN/m^2 (4.0 tons/ft^2) under any live load up to and including MLC70 (T and W), including an allowance of 1.2 V, dead load and the most significant secondary load. In extreme conditions, allowing for bridge movement, ramp bearing length can reduce to 0.25 m (10 in.) before reinstatement, but corresponding pressures shall not exceed 1,140 kN/m^2 (11.9 tons/ft^2) under the same load.

A4.2.6.2 Support {General Support} bridges shall be designed to bear uniformly on a projected length of 1.0 m measured from the effective end of bridge (which might exclude approach ramps). Under such conditions maximum bearing pressures should not exceed 425 kN/m^2 (4.4 tons/ft^2) under any live load up to and including MLC70 (T and W), allowing for the dynamic effects of multiple vehicles, dead load and the most significant secondary load. In extreme conditions, allowing for bridge movement, effective bearing length can reduce to 0.5 m (1 ft, 8 in.) before reinstatement, but corresponding pressures shall not exceed 850 kN/m^2 (8.9 tons/ft^2) under the same load.

A4.2.6.3 In special circumstances involving combination (overlapping) bridging or overbridging, extreme bearing pressures shall not exceed 40,000 kN/m^2 (5,800 psi) and the effects of local crushing must be considered at the interface between structures. The same consideration of local damage must be given to bearing on hard, high spots when bridges are 16 supported on the nominal full bearing area as defined above.

A4.2.7 Depth of Bridge at Ramp Toe

Condition	Assault bridge (close support)	Support bridge (general support)
Maximum	100 mm	75 mm
Desirable	50 mm or less	Minimum possible

A4.2.8 Bridge Deck Slopes

The allowable longitudinal slopes for a bridge with level supports and no applied loads, A_i, are given in the following table. The transverse slope allowing for the support conditions of section A4.2.5 and the unfactored fully eccentric vehicle load V, with impact should not exceed 1 in 10.

Description	Assault bridge (close support)	Support bridge (general support)
Short ramp or sloping end of bridge up to 3 m(9 ft 10 inch) long:		
Maximum	1 in 5	1 in 7
Desirable	1 in 7 or less	1 in 10 or less
Ramp or sloping end of bridge longer than 3 m (9 ft 10 inch):		
Maximum	1 in 6	1 in 9
Desirable	1 in 10 or less	1 in 14 or less
Change of slope on bridge other than at sloping ends:		
Maximum	1 in 6	1 in 10
Desirable	1 in 10 or less	1 in 20 or less

A4.2.9 Wind Velocity and Pressure

The wind velocities and pressure are the maximum values to which the bridge should be designed.

Design Condition	Wind velocity (v) m/s	(knots)	Wind pressure (Wp) kN/m^2	(lbf/ft^2)
During construction/ launching	15	29.2	0.138	2.88
On bridge and crossing vehicle	20	38.8	0.245	5.11
On bridge alone	30	58.3	0.552	11.51

A4.2.10 Vehicle Design Crossing Speed

Essential speeds are the maximum speeds under normal field conditions and the speeds up to which bridges must be tested:

Vehicle design speed	Up to MLC 30	Above MLC 30
Essential	25 km/h (15 mi/h)	15 km/h (10 mi/h)
Desirable	40 km/h (25 mi/h)	25 km/h (15 mi/h)

A4.2.11 Impact

Vehicle induced loads will be increased by the following factors to cover crossing speeds up to 25 km/h (15 miles/h):

Location	Impact factors	
	Bending moment and deflection	Shear force
Interior	1.15	—
Ramp	1.2	1.2

It should be noted that these values cover modern suspension vehicles for the desirable velocity and old suspension and high pitch inertia vehicles for the essential velocity according to Section A4.2.10. The given factors are typical values so that for extreme cases a more detailed investigation for design is recommended. An increase of 15 per cent for impact will be added to the bridge dead load, *D*, and launching equipment if appropriate during launching.

The maximum included static load multiplied by the impact factor results in the maximum induced dynamic load.

A4.2.12 Mud Load (*M*)

The following load will be used when calculating the effects of mud on the roadway surface is 0.75 kN/m^2(76 kp/m^2, 15.67 lbf/ft^2).

A4.2.13 Snow and Ice Load (*S*)

The following load will be used if it has a greater effect than the mud load, *M* [300 mm (12 inch) of loose snow of areal density] is0.37 kN/m^2 (7.7 lb/ft^2).

A4.2.14 Footwalk Loading (*F*)

Footwalks are those structures which are attached to existing structures e.g. as add-on kits or stand alone structures.

Footwalks are intended primarily for the support of crossing troops and secondarily in support of local pedestrian traffic for local commerce. Loadings will include the fully outfitted combat soldier and/or could additionally include bicycles, motorcycles, all terrain vehicles, livestock and horses. The value of the design loading to be considered on the footwalk could be adjusted depending on the intended use of the structure and the ability to restrict types of traffic.

A4.2.14.1 The main members of the footwalk shall be designed for a maximum live loading of 4.0 kN/m^2 (83.56 lbf/ft^2) for spans up to 30 m (98 ft, 5 in.). The load will then be reduced linearly to 3.0 kN/m^2 (62.67 lbf/ft^2) for spans up to 60 m (196 ft, 10 in.). For spans beyond 60 m (196 ft, 10 in.), the load will remain constant. Main members shall be defined as those members, which comprise the main structural elements of the footwalk, e.g., girders, trusses, arches etc.

A4.2.14.2 The secondary members shall be designed for a maximum live load of 4.0 kN/m^2 at all spans. Secondary members shall include decks, supporting floor systems, secondary stringers, floorbeams and connections to the main members.

A4.2.14.3 The force to be considered for a laden soldier will be 1.27 kN (286.65 lbf), which is the combination of the weight of the individual soldier at 0.88 kN (198.45 lbf) and the weight of his backpack at 0.39 kN (88.2 lbf).

A4.3 COMBINATION BRIDGING

A4.3.1 Combination bridging may be used in wet or dry gaps where the clear span to be bridged exceeds the span capability of a single bridge system. In wet gaps, the use of combination bridging into water shall be permissible under the following conditions: Maximum surface water speed at mid-stream not to exceed 1.5 m/s (2.9 knots). Under bridge dead load alone, water level shall not to be within 100 mm (4 in.) of any trafficable deck surface. Combination bridges must not be launched unless there is some non-metallic interface between the bridges to

spread the anticipated live load and prevent slipping in a wet environment under live vehicle trafficking.

A4.3.2 The longitudinal slope of any span deployed in a combination must not exceed the capability of a simply supported single span under the same load condition. The longitudinal slope is defined as the slope of an imaginary line joining the home and far bank toe pins of a single span bridge.

A4.3.3 For the purpose of designing combination bridges, the launch plane of the launch vehicle is defined as the nominal extension of the surface on which the launch vehicle tracks or wheels are located.

A4.3.4 Under dead load conditions, acute angles between the underside bottom chord of a subsequent span, and the deck of the underlying span are to be greater than 3 degrees to allow for subsequent deflection under live load, and avoid the possibility of knife-edge loading.

A4.3.5 Ingress and egress should allow vehicles a straight run on and off the bridge to minimize the need for slewing.

A4.3.6 The launching of the first bridge of a combination bridge is restricted to a transverse slope of 1 in 20 (5 per cent). If opposing bankseat cross slopes result in a combined angular deviation of more than 1 in 20 (under dead load), instability could result at bridge intersections.

A4.3.7 Conditions of the bed of the river or gap must be determined if the combination bridge is to be laid with minimal risk. If any doubt exists as to the condition of the bed, a survey involving divers must be undertaken. The bed should be free from obstructions and firm enough to support the bridge toes.

A4.3.8 The depth of any silt or soft material must be known, and some assessment made of likely sinkage. Whilst a uniform bed is desirable, it must be accepted that live load trafficking or scouring from hydrodynamic forces can produce settlement. The limiting cross slope and irregularities for bridges used in combination shall be no worse than the limiting support conditions prevailing for simply supported single spans.

A4.3.9 The toes of a second or third span in a combination might be restricted to specific locations along the length of the first bridge. This might be necessary to avoid structural overloading of the first span in shear near the ramps, or in bending as a result of the additional dead load of subsequent bridges.

A4.3.10 The maximum lateral misalignment permitted between bridges shall be no more than 75 mm.

A4.3.11 For second and subsequent spans, due account must be taken of possible bridge movement as a result of vehicle crossings, particularly if bridges are on a downward longitudinal slope, the junction between bridges is wet or under water, or likely to be subjected to significant (>50) crossings.

A4.3.12 In order to minimize the need to reinstate combination bridges due to bridge movement, it is advised that where the overall bridge length allows, the toe is positioned up to 2 m (6 ft, 7 in.) back from the limiting toe position, measured in the direction opposite to that trafficking. Alternatively, there should be some system for the anchorage of bridges from under armor, or the remote attachment of one bridge to another to prevent slippage occurring.

A4.3.13 The amount of bridge movement is dependent on various factors and conditions such as mass of the vehicle, type of vehicle, clear span of the bridge, degree of longitudinal bridge slope, ground bearing capacity and friction conditions at the supports. Generally, the heavier the vehicle and the greater the clear span, more bridge movement is to be expected. Bridges must be reinstated if the anticipated throughput of traffic results in sufficient movement to reduce bearing areas to minimum safe limits. The minimum safe bankseat bearing length for Close Support Bridges (CSBs) shall be taken as 0.25 m (10 in.).

A4.4 PIERS

A4.4.1 Dimensions

A4.4.1.1 In the absence of a User requirement, the following dimensions are recommended for the design of piers and trestles which might be installed in wet gaps:

Measurements	Assault bridge (close support)	Support bridge (general support)
Gap depth		
Essential	4 m (13 ft, 1 inch)	7m (23 ft)
Desirable	5 m (16 ft, 5 inch)	12 m (39 ft, 4 inch)
Water Depth:		
Minimum	3 m (9 ft, 10 inch)	6 m (19 ft, 8 inch)
Desirable	4 m (13 ft, 1 inch)	6 m (19 ft, 8 inch)

A4.4.1.2 In addition, there is to be a minimum clearance of 100 mm (4 in) between any point on the trafficable deck surface and the surface of the water, when the total bridge system is deployed without live load.

A4.4.1.3 In the case of combination bridges on piers or trestles, due consideration must be given to the obtuse angle (θ) between bridge deck surfaces (which could affect trafficability), the acute angle (α) between the deck of a first span and the undeflected bottom chord of a subsequent span (which could produce 'knife–edge' loading), and the relative overlap (δ) between bridges (which could be reduced with trafficking as a result of bridge movement, Fig. 4.2).

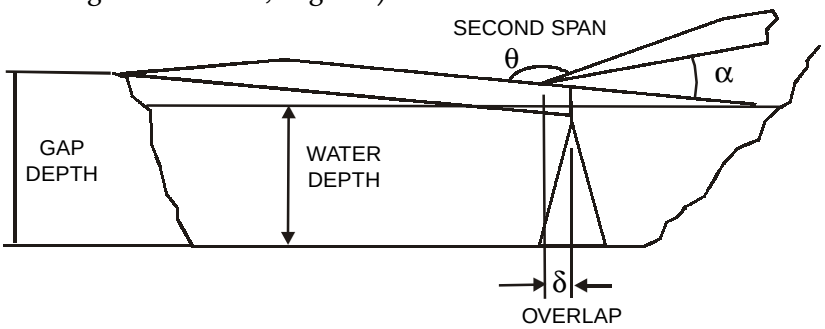


Figure 4.2. Combination bridge on piers.

A4.4.1.4 Minimum suggested values for these parameters are:

$\theta = 149.0$ degrees, $\alpha = 3.0$ degrees, $\delta = 0.75$ m (2 ft, 6 in.)

A4.4.2 Grillage Bearing Pressure

Maximum: 160 kN/m^2 (1.7 ton/ft^2). Sinkage is acceptable consistent with stability and recovery.

A4.4.3 Current Speeds

The current speeds for piers are the same as those given for floating bridges and rafts (Section A4.4.1).

A4.4.4 Pier Support

These should articulate in any direction to allow a longitudinal and transverse bridge slope of at least ± 1 in 10 (± 10 per cent) under live vehicle loading.

A4.5 FLOATING BRIDGES AND RAFTS

A4.5.1 Current Speeds

Condition	Speed
Construction and normal use	2.5. m/s (4.9 knots)
Unladen equipment survival	
Minimum	3.5 m/s (4.9 knots)
Desirable	5.0 m/s (9.7 knots)

A4.5.2 Raft Speed – Laden

Condition	Speed
Minimum	2.5 m/s (4.9 knots)
Desirable	3.5 m/s (6.8 knots)

A4.5.3 Worst Case Shallow Water, Fast Current Condition

Midstream: 2 m (6 ft, 7 in.) of water running at 2.5 m/s (4.9 knots).

A4.5.4 Worst Case Shallow Water Condition at Bank for Ramp and Flotation

River bed slopes down 1 in 7 from water's edge.

A4.5.5 Bank-Height/Ramp-Elevation Ranges

Condition	Range
Upward:	
Minimum	+1.5 m (4 ft, 11 inch)
Desirable	+2.0 m (6 ft, 7 inch) (Relative to water level.)
Downward:	Bottom of ramp toe should be level with bottom of main floating structure.

The ramp slopes on rafts and bridges should not exceed the values given in section A4.2.8 for the worst condition of loading.

If these bank heights are used for launching floating equipment, it is not realistic to combine them with the worst shallow water depth in section A4.5.4. A water depth of 2.0 m (6 ft, 7 in.) can be assumed 8.0 m (26 ft, 3 in.) from the water's edge.

A4.5.6 Pontoon Bottom-Skin Load

The pontoon bottom-skin load should not exceed 96 kN/m^2 (9800 kp/m^2, 2,005 lbf/ft^2).

A4.5.7 Minimum Freeboard

The following minimum freeboard values with the maximum MLC vehicle load(s) fully eccentric are considered adequate for normal equipment configurations at the design current speed. See section A4.5.1.

Floating Support	Minimum freeboard of pontoon			
	Bow		Side	
	(mm)	(inch)	(mm)	(inch)
Pneumatic floats	100	(4)	0	(0)
Rigid open pontoons	225	(9)	125	(5)
Rigid closed pontoons	150	(6)	100	(4)
Rigid, continuous closed pontoons	50	(2)	0	(0)

A4.5.8 Trim

A floating bridge or raft with a vehicle at permitted eccentricity should not trim so that the deck slope is more than 1 in 20 under the worst permitted hydrodynamic conditions.

A4.5 TYPICAL VEHICLE DATA FOR DESIGN

	MLC	Height of Centre of gravity (CG) (m)	side wind surface (m^2)	Height of centre of pressure (m)
Tracked	4	1.02	7.32	1.18
	8	1.05	8.23	1.20
	12	1.07	9.13	1.23
	16	1.09	10.04	1.25
	20	1.12	10.94	1.28
	24	1.14	11.85	1.30
	30	1.18	13.33	1.34
	40	1.24	15.47	1.40
	50	1.30	17.74	1.47
	60	1.36	20.00	1.53
	70	1.42	22.26	1.59
	80	1.48	24.53	1.65
	90	1.54	26.79	1.72
	100	1.60	29.06	1.78
	120	1.72	33.59	1.90
	150	1.90	40.45	2.09
Wheeled	4	2.40	6.12	2.20
	8	2.40	12.24	2.20
	12	2.40	20.24	2.20
	16	2.40	24.17	2.20
	20	2.40	32.66	2.20
	24	2.40	38.10	2.20
	30	2.40	45.00	2.20
	40	2.40	45.00	2.20
	50	2.40	45.00	2.20
	60	2.40	45.00	2.20
	70	2.20	45.00	2.20
	80	2.00	45.00	2.20
	90	2.00	45.00	2.20
	100	2.00	45.00	2.20
	120	2.00	45.00	2.20
	150	2.00	45.00	2.20

A4.6 TEMPERATURE AND ENVIRONMENT

The environmental effects due to the required categories must be considered (Stanag 2831 withdrawn). Thermal stress and long term degradation due to temperature and humidity must be considered.

A5 – LOADS AND LOAD COMBINATIONS

A5.1 GENERAL

The designer will use the most critical loading obtained from Section A5.3, using the values given here or detailed in section A4 and the combinations given in Section A5.4. The worst support conditions must be taken into account.

A5.2 DEFLECTIONS

Deflections are not limited directly by this code but must be considered when they cause changes in loading, affect fit or alignment, or affect the use of equipment.

A5.3 MILITARY BRIDGE LOADS

A5.3.1 Dead Load (*D*)

The structure dead load, *D*, shall consist of the weight of the complete bridge for the structure in place or of the appropriate bridge components.

A5.3.2 Vehicle Load (*V*)

A5.3.2.1 The vehicle load *V*, is represented by the hypothetical vehicle of the required load class depicted in Appendix C of Stanag 2021. The most critical loads induced by any of the following with the impact factor will be used:

The hypothetical tracked vehicle

The hypothetical wheeled vehicle

The hypothetical axle load

The hypothetical single-wheeled loads

If a vehicle other than the hypothetical Stanag vehicle is used, problems will be encountered with variations in load class or the load to give the correct bending moment or sheer. These occur due to changes in bridge length and vehicle width.

A5.3.2.2 For tracked vehicles, load will be applied as follows for each track: for military load class (MLC) 30 and above, there will be

6 contact areas and for MLCs lower than 30 there will be 5 contact areas. These represent the road wheels and must be fitted into the hypothetical track length allowing for the contact area length. The width of each contact area is taken as the hypothetical vehicle track width and the contact area length along the track is taken so that the working load bearing pressure:

$P_b = 0.6 + \text{MLC}/100 \text{ N/mm}^2$

If the number of contact areas is reduced or increased, p_b must be changed accordingly. For wheeled vehicles, the wheel load will be applied on a contact area, with the nominal tire width and laod of the hypothetical vehicle (Appendix C of Stanag 2021) which will produce a contact pressure of 1.25 times the tire pressure at working laod not to exceed 1100 kN/m^2 (112 kp/cm^2, 160 lbf/in^2).

A5.3.2.3 Consideration should be given to changes in individual wheel and tank-track bogie loads as vehicles pitch or negotiate changes in slope.

A5.3.3 Mud load *(M)*

The mud load, *M*, in the design parameters will be considered over the roadway area. Reductions in loading may be made for proven self-cleaning decks. Accumulations of mud on vehicles will not be considered. It is assumed that mud is removed from bridges before they are recovered or retrieved. If this is not possible, a percentage of the mud load, *M,* should be included in the weights for retrieval purposes. This percentage is a function of the particular bridge design and will range from 10 to 25 per cent of the total. The impact factor should be considered in addition.

A5.3.4 Snow and Ice Load *(S)*

The snow and ice load, *S,* as specified in the design parameters is applied uniformly over the bridge and flotation plan area. The load, *S,* will not be applied unless the effect is greater than the mud load, *M,* in which case it will be used

instead of the mud load *M*. Accumulation of snow and ice on vehicles will not be considered.

A5.3.5 Impact

To provide for impact on clear-span (fixed) bridges, the vehicle induced load *V,* will be increased as required by the design parameters. The impact factor will be applied to the bridge dead load, *D,* for the bridge launching condition only as required by the design parameters. For floating bridges, the impact factor in the centre section will be 1.05 for ramp (landing bay) slope of 0.0°. It may increase to 1.3 for either the bending moment at higher crossing speeds or at more extreme ramp slopes for the shear force in the ramp. These effects can extend up to one vehicle length towards the centre of the bridge and should be investigated.

A5.3.6 Eccentricity

Bridge design will provide for normal crossing of the load, *V,* anywhere on the roadway surfaces. The critical position will be that which produces the greatest stress conditions as determined by static analysis. Bridge cross slopes and deflections and movements of the vehicle centre of gravity (*CG*) must be allowed for.

A5.3.7 Spacing

Design will be based on a minimum clear distance between vehicle contact points of 30.5 m (100 ft) or more if critical during the crossing of rated loads.

A5.3.8 Braking and Acceleration

Braking and acceleration forces, *B,* of the braking factor times vehicle load, *V,* will be included as a longitudinal horizontal load. Tracked vehicle skewing forces of 0.1 times vehicle load, *V,* will be included as a transverse horizontal load (braking and skewing forces are not additive).The vehicle load, *V,* does not include the impact factor in these cases. These loads are assumed to act at the deck surface. The braking factor is reduced for more than one vehicle on a bridge as follows:

No. of vehicles on bridge	Total braking factor
1	0.65
2	0.9
3	1.15

Braking factors are bridge system and material dependent. The braking factor for materials other than between aluminum and rubber must be determined through testing.

A5.3.9 Footwalk

Footwalks will carry the uniformly distributed load, *F,* shown in the design parameters.

A5.3.10 Curbs (Kerbs)

If provided, curbs will be of sufficient height and strength to restrain the maximum wheeled vehicle from sliding off the bridge at a 1 in 10 (10 per cent) side slope and zero coefficient of friction. For tracked vehicles, curbs will only be considered a psychological restraint.

A5.3.11 Wind

A5.3.11.1 The appropriate wind load, *W,* will be applied to the bridge during construction, launching, and recovery, to the completed bridge and vehicle(s) during crossing; and to the bridge alone (maximum wind load). Wind velocities and pressures are given in the design parameters see section A4.

A5.3.11.2 The wind pressure, *Wp* is determined from the following formulas:

$$Wp = 0.613\ v^2\ \mathrm{N/m^2} \text{ with } v \text{ in m/s}$$

$$0.0625\ v^2\ \mathrm{kp/m^2} \text{ with } v \text{ in m/s}$$

$$0.00347\ v^2\ \mathrm{lbf/ft^2} \text{ with } v \text{ in knots}$$

A5.3.11.3 Allowance must be made for the type of bridge construction, drag, shadow effects, and angle of incidence. It may be necessary to consider a lower MLC vehicle/maximum wind area in section A4. The following drag coefficients should be used unless more accurate values are established: (a) Bridge and launching structure–1.6 and (b) Vehicles–1.4.

A5.3.12 Additional Loads on Floating Equipment

The following additional loads and conditions must be considered for floating bridges, rafts, and causeways:

Grounding pontoons on one side including the effect of vehicle load on the structure, the bottom- skin load given in the design parameters, and the possibility of bridging between two groundings.

–Possible locking of articulating connections.

–Increasing stress resulting from the fact that on a floating bridge a single vehicle may impose a greater stress than several vehicles at the minimum spacing, and there may be a critical spacing and/or speed related to the natural crossing water wavelength or band-reflected wave trough.

A5.3.12.1 On a raft the vehicle loads, *V,* may be concentrated with no spacing and should be considered stationary, neglecting impact.

A5.3.12.2 Drag is the horizontal component of hydrodynamic force, Q. For a raft, this force includes the propulsion force which may act in any direction. For a floating bridge where propulsion units or anchors counteract drag, the following effects must be allowed: failure of alternate propulsion units or anchors; failure of alternate anchors, if the anchor spacing is not less than 14.0 m (45 ft, 11 in.); or failure of all anchors. This assumes the remaining propulsion units or anchors can take the increased load. This effect is also considered to cover the effect of floating debris on unprotected structures.

A5.3.12.3 Draw down is the vertical component of the hydrodynamic force, Q, caused by the shallow water, fast current effect.

A5.3.12.4 The hydrodynamic forces, Q, depend on the configuration of the equipment and the hydrodynamic conditions. Such forces should be determined by theoretical analysis or by model tests. The design parameters give some guidance to hydrodynamic conditions. The hydrodynamic forces, Q, can be increased by the following effects: (i) Interference of flow caused by little or no clear space between pontoons, increasing the flow velocity under the pontoons and possibly the

upstream head, (ii) Longitudinal wave formation initiated by vehicle crossing, causing loss of water under the inshore pontoon.

A5.3.12.5 The unbalanced load due to ice forming from spray or during launch shall be accounted for by multiplying the exposed surface area to one side of the centreline times 27 N/m^2 (2.75 kp/m^2, 0.56 lb/ft^2). This represents an ice load of 3 mm (0.12 inch) thickness.

A5.3.13 Pier Load

A pier shall be considered as a clear-span bridge component allowing for the hydrodynamic loads at the specified currents speeds. The current direction should be allowed to deviate 20 ° from the normal line of approach.

A5.4 LOAD COMBINATIONS

See section A2.2 symbols, for definition of symbols. See section A6, Safety for details of the functions below.

A5.4.1 Clear-Span Bridges

A5.4.1.1 During construction, launching, and recovery:

$P = R(D, W, M)$

Launch drive loads and working parties must also be considered.

A5.4.1.2 In Place

For normal bridge use, $P = R(D, V, W, M, B, F, S)$

For unloaded bridge survival, $P = R(D, W, M, S)$

Survival is no permanent set or overturning.

A5.4.1.3 Bridges with Piers

In addition, the horizontal components of the hydrodynamic force, Q, must be considered in the above load combinations.

A5.4.2 Floating Bridges and Rafts

A5.4.2.1 During construction, launching, and recovery:

$P = R(D, Q, W)$

A5.4.2.2 In Place

For normal use, $P = R\,(D, V, Q, W, M, S, B, F)$
For unloaded survival, $P = R(D, Q, W, M, S)$.

A6 – SAFETY

A6.1 GENERAL

Safety is covered as follows: derivation of the design load; safety coefficients for working stress; flotation and stability; fatigue safety factor; and safety against overturning or rotation

A6.2 DESIGN LOAD (*P*)

The design load, P, is derived as follows using the appropriate load combination of dead load, D, and applied loads A_1, A_2 in order of decreasing severity (where A_2 is the largest of any secondary loads):

$$P = D + A_1 + A_2$$

This means that all loads after the third are ignored. They are generally not significant when compared with A_1 and all the loads are unlikely to reach extreme values together. Vertical and transverse load cases are to be considered as these may have different orders of loads. Similarly there may be different orders of loads for different components. For preliminary analysis, dead load, D, and vehicle load, V, may be factored by 1.15 at MLC 30 to cover all other loads. For higher load classes, this factor can be linearly reduced down to 1.075 at MLC 60 and above.

A6.3 SAFETY COEFFICIENTS AND COMBINED STRESSES FOR METAL

A6.3.1 Allowable Stresses

The design load, P, will not cause stresses exceeding the following appropriate values.

A6.3.1.1 Bending and/or Tension

The lesser of the following will be used:
Ultimate Strength/1.5 or
0.2 % Proof Stress or Yield Stress/1.33.

A6.3.1.2 Shear

The value from A6.3.1.1 multiplied by 0.6.

A6.3.1.3 Bearing

The value from A6.3.1.1 multiplied by 1.33.

A6.3.1.4 Buckling

Where failure can occur because of buckling, the following allowable stress will be used:

Buckling Stress/1.5

A6.3.2 Combined Stresses

A6.3.2.1 Calculation is based on linear elastic theory

A6.3.2.2 Combined axial stresses due to bending and axial tension or compression, or additive axial stresses due to bending in two planes at right angles will satisfy linear superposition:

$\sum$(actual axial stresses due to design load σ_x) $\leq$ allowable stresses

For compression, buckling may also have to checked.

A6.3.2.3 Yielding Theories of Failure

For materials with ductile behaviour, Octahedral Shearing Stress Theory will be used

$$\sigma_v = \sqrt{\sigma_x{}^2 - \sigma_x \sigma_y + \sigma_y{}^2 + 3\sigma_s^2}$$

σ_v may not be greater than 0.9 times the allowable stresses.

For material with brittle behaviour, Maximum Principle Stress Theory will be used:

$$\sigma_v = \frac{\left(\sigma_x + \sigma_y\right) \pm \sqrt{\left(\sigma_x + \sigma_y\right)^2 + 4\sigma_s^2}}{2}$$

σ_v may not be greater than the allowable stresses.

A6.3.3 Limit State Design (LSD) (Provisional)

Structures will satisfy both the overload check and ultimate check, as defined in Appendix I- Limit State Design (Provisional) (of Trilateral Design Code).

A6.4 SAFETY COEFFICIENTS AT WORKING LOAD (*P*) FOR COMPOSITES AND ADHESIVES

A6.4.1 Safety Coefficients for Working Conditions for Composites

The design load, *P*, shall not cause stresses or strains exceeding the following appropriate values.

A6.4.2 Allowable Strain

Under the maximum working load, the strain in any fiber direction should not exceed 50 per cent of the minimum guaranteed fiber strain.

A6.4.3 Multiaxial Stresses

The stress level in a lamina should be limited based on an appropriate lamina failure criterion, incorporating a safety margin. The Tensor Polynominal Hoffman-Hill criteria or Tsai-Wu criterion as given next may be used. Alternative criteria must be shown to be appropriate prior to application. It might be necessary to consider other than first ply failure

$$1.5(T_1\sigma_1 + T_2\sigma_2) + 1.5^2(T_{11}\sigma_1^2 + T_{22}\sigma_2^2 + T_{33}\sigma_3^2 + 2T_{12}\sigma_1\sigma_2) \leq 1$$

where 1.5 is the safety factor using A-values. If A-values have not been established, 1.2 × 1.5 = 1.8 should be used.

σ_1 = normal stress in fiber direction

σ_2 = normal stress perpendicular to the fiber in the plane of the lamina

σ_3 = in-plane shear

T_1 = in-plane shear stress

T_1, T_2, etc are strength parameters determined by test

$$T_1 = \frac{1}{X_T} - \frac{1}{X_C}, T_2 = \frac{1}{Y_T} - \frac{1}{Y_C}, T_{11} = \frac{1}{X_T X_C}, T_{22} = \frac{1}{Y_T Y_C},$$

and

$$T_{33} = \frac{1}{U_S^2}$$

T_{12} cannot be determined unambiguously; T_{12} may be taken as zero or $-1/2\sqrt{T_{11}T_{22}}$ unless there exists specific information to justify a different value. X_T, X_C, Y_T, and Y_C are the minimum tensile and compressive failure strength values of the unidirectional layer in directions parallel to and perpendicular to the fiber direction, and U_s is the minimum in-plane shear strength. In addition to the limitation on ply stress level, the tensile and compressive stress levels in the laminate composite should be limited to 2/3 of the corresponding minimum guaranteed laminate strength levels.

A6.5 FLOTATION AND STABILITY

The safety of floating bridge and rafts depends also on reserve flotation and stability. Since these are related to the equipment configuration and usage and to hydrodynamic conditions, exact rules are difficult to make. The following points should be used as a guide.

A6.5.1 It is desirable that when flotation is damaged or holed, it should be capable of at least supporting the dead load, *D,* by compartmentalizing or other means. Flotation must be provided for more than the working load, *P*. Approximately 20 per cent reserve of buoyancy in still water is recommended, but load distribution between flotation units also should be considered. Buoyancy shape must allow for wave formation.

A6.5.2 Components as they are launched, part assemblies, and the final assembly must have stable equilibrium for normal eccentric loading in the required hydrodynamic conditions. The individual component must accept a load of 1.35 *Pc* placed on

the gunwale without becoming unstable. *Pc* is the component stability design load and must include the relevant portion of the dead load, D, and the maximum number of soldiers likely to be on the pontoon during construction. For open components when flooded, the load A_1 is a soldier, 0.89 kN (91 kp, 200 lbs), and a pump which can be taken as 0.25 kN (25 kp, 55 lbs) in the absence of a design figure. For complete equipment supporting a vehicle, the empirical factor of safety on stability is that the metacentric height of the loaded flotation must be equal to or greater than 5 times the distance from the equipment centreline to the maximum load class vehicle centre of gravity (CG), when the outside line of the track/tire coincides with the edge of the roadway surface.

A6.6 Fatigue Safety Factor

See Section 7, Fatigue

A6.7 Safety against Overturning or Rotation

During construction, launching, and recovery, there must be a minimum factor of safety against overturning or rotation of 1.20. This is assumed to include impact.

A6.8 LIFTING AND ANCHORAGE SAFETY

A6.8.1 Lifting equipment which has unrestricted use must comply with civilian regulations and be marked with the safe working load.

A6.8.2 Lifting eyes should comply with civilian or military regulations and be marked with the safe working load.

A6.8.3 Lifting points designed as part of an equipment must have minimum safety factor for proof load of 3.2 for equipment mass from 230 to 9,080 kg (0.25 to 10.0 tons) or 2.3 for equipment mass more than 9,080 kg (10 tons). They must have a minimum safety factor for ultimate load of 4.8 for equipment mass 230 to 9,080 kg (0.25 to 10.0 tons), or 3.45 for equipment mass more than 9,080 kg (10 tons). Allowance must be made for the number of points used and/or for the number of items to be lifted. These safety factors include inertia loads due to

acceleration.

A6.8.4 Tiedown fittings should have a minimum safety factor for proof load of 4 in the fore and aft direction, 2 upwards, and 1.5 in the lateral direction. The ultimate load should be 1.5 times the proof load. A requirement for air transport may also have to be considered.

A6.8.5 Steel wire rope cables, slings, and assorted fittings not covered by section 6.8.1 should have a minimum safety factor of 3 on the breaking load.

A6.9 AIR TRANSPORT SAFETY

A6.9.1 Air Portability

Attachment points are required or the facility to provide the following ultimate restraints: forward 4.0 g (an absolute minimum of 3.0 g) is allowed in transport aircraft without passengers. All other horizontal directions are 1.5 g and upwards 2.0 g. 44.50 kN (4,539 kp, 10,000 lbf) ultimate load tie down chains are used.

A6.9.2 Air Dropping

Attachment points are required or the facility to provide the following ultimate restraints: forward 4.0 g, upward 5.0 g, and all other directions, 3.0 g. The medium stressed platform has 22.24 kN (2,268 kp, 5,000 lbf) ultimate load tiedowns and the heavy stressed platform, 44.50 kN (4,539 kp, 10,000 lbf) ultimate.

A6.9.3 Helicopter Lift

A single lift point must take 4.3 g ultimate. Two points must each take 2.2 g; three points 1.5 g, and four points 1.25 g ultimate. Ideally, a four-leg sling should be used with the lift points as far from the CG as possible and above it. The included angle of the sling is not to exceed 120°. The load should include down draught (maximum value is 0.287 kN/m^2, 29.0 kp/m^2, 6.0 lbf/ft^2) allowing for fuselage shadow. Drag and negative lift must also be considered.

A7 – FATIGUE

A7.1 SCOPE

Design based on sections A5 and A6 may not result in adequate fatigue life. Structures must be checked or designed in accordance with this section, and the required life must be confirmed by test as required by section A8. The material fatigue data requirements are in Section A3, section A7, covers load spectrum parameters, fatigue design load range, damage tolerant design, and alternative designs. Appendix H - Safety Factors on Required Life *N* for Design and Test (of Trilateral Design Code), summarizes the safety factors given in this and the following section, Section A8–Testing.

A7.2 LOAD SPECTRUM PARAMETERS

A7.2.1 The following parameters affect the fatigue life of military bridges and their launching equipment. The combined parameters, with the frequency of application, form the load spectrum.

- Vehicle spectrum, number of crossings with actual laden vehicle weights
- Gap/span spectrum with associated number of crossing vehicles
- Number of launches
- Impact
- Eccentricity
- Bridge support conditions
- Modular bridge component location variation with each build

A7.2.2 Information is not available at present for all of the above parameters, and it is not possible to obtain load spectra for military bridges. For the present, the life required will be expressed as a specified number of crossings *n,* of the

maximum load class over the maximum span of the bridge and a specified number of launches. No approximate launching load spectrum has been established.

A7.2.3 When modular bridges can be constructed in different forms and various MLC/span combinations, the most fatigue damaging construction based on normal usage and stress level should be considered.

A7.2.4 Use for different MLCs and bridge spans may be related approximately to the constant amplitude parameters; stated in paragraph A7.2.2, by the Palmgren-Miner or linear damage rule.

$$\frac{n_1 \text{ crossings (cycles at stress } \sigma_1)}{N_1 \text{(fatigue life at stress } \sigma_1)} + \frac{n_2 \text{ crossings (cycles at stress } \sigma_2)}{N_2 \text{(fatigue life at stress } \sigma_2)} + \ldots + \frac{n_i \text{ crossings (cycles at stress } \sigma_i)}{N_i \text{(fatigue life at stress } \sigma_i)} \leq 1$$

where the stress σ_1 and fatigue life N_i are from given MLCs/spans over which the n_i crossing occurs. Preferably, if a realistic load spectrum can be established, programmed fatigue test representative specimens should be used to establish a more accurate damage relationship.

A7.3 FATIGUE DESIGN LOAD RANGE (P_{FAT})

The fatigue design load range, P_{FAT}, is the unfactored vehicle load multiplied by a dynamic factor covering eccentricity and impact. This dynamic factor for design can be established by tests or from experience. From current equipment the following mean factors may be used: clear span bridges, 1.075; link reinforcement, 1.15; and floating bridge girders 1.035. It is assumed that applied loads other than vehicle loads are not significant and bridge supports are generally level. Certain components may have to be designed for other load conditions. A factor for launching loads still has to be established.

A7.4 DAMAGE TOLERANT DESIGN

(Metals only. Special consideration for composites)

A7.4.1 Because of the scatter in fatigue performance and the possibility of use beyond required minimum life, there is a risk that a bridge will fail in service. Damage-tolerant design should ensure that when fatigue cracking occurs in service the remaining structure can sustain the maximum working load P without failure until the damage is detected. A safety factor of 1 is acceptable (The same should apply to corrosion or accidental damage).

A7.4.2 The stress range due to the fatigue design load range P_{FAT}, will not exceed the stress range from the most suitable minimum curve for stress/number of cycles (S/N) at $1.5n$ or from the most suitable mean curve at 1.5 x $1.5n$ ($2.25n$). In addition, a check must be made to ensure that the maximum stress due to the design load, P, does not exceed the lower value of the allowable stress from Section A6. If possible, it should be established that for a particular detail, the factor should be 1.5 on minimum or 2.25 on mean.

A7.4.3 The following design features should be used to achieve damage tolerance.

- Selection of materials and stress levels to provide a low rate of crack propagation and long critical crack length
- Provision of multiple load paths
- Provision of crack- arresting details
- Provision of readily inspectable details

Establish a fracture control plan for safe life and safety critical components which are not fail safe, giving inspection methods, material, data requirements, assumed initial crack size, required inspection frequency, and the like.

A7.4.4 Damage tolerance depends on level of inspection the user is prepared to apply to the structure and is not automatically ensured by replaceable components. Inspection of equipment must be planned to ensure adequate detection and monitoring

of damage and to allow for repair or replacement of components. This must be confirmed during testing (Section B8-Testing). The following factors must be considered:

- Location and mode of failure
- Remaining structural strength
- Detectability and associated inspection technique (This should be based on the largest flaw not likely to be detected rather than the smallest it is possible to find)
- Inspection frequency
- Expected propagation rate allowing for stress redistribution
- Critical crack length before repair or replacement is required.

A7.4.5 It may be necessary to test fatigue critical components or details in the laboratory, particularly if suitable minimum curves are not available or the mode of cracking cannot be anticipated. If there are a limited number of samples, or a structure is tested, so that there is only one failure from a number of equally loaded samples, the required life factor from the table given in Section B8.8.4 should be used. The test results can be analysed statistically if there are five or more samples. The lowest sample life to failure should be at least the minimum design life (1.5 n).

A7.4.6 If a component, or a structure subject to the same loading, includes a critical safe life element (see Section A7.5) that relies on a damage tolerant element to indicate that fatigue life is expended, the minimum life of the safe life detail must exceed the maximum life expected from the damage tolerant detail.

A7.5 ALTERNATIVE DESIGNS

Damage tolerant equipment is preferred. The most economic structure should be produced if it is designed to a minimum required life and provision is made for regular inspection. However, there may be cases where a regular inspection is not possible or the user does not wish to take on the commitment and the resulting penalties are acceptable.

There are then three further design systems which can be used. They are not generally recommended unless specifically required but are included to show the alternatives available.

A7.5.1 Monitored Usage Safe Life

Regular inspection for fatigue cracks is not required or may not be possible. The design and test factors for damage tolerant design are used, but to allow for monitoring and cumulative cycle ratio errors, the design life is factored by an additional 1.5 giving 2.25 n on a minimum curve or 3.37 n on a mean curve. The component or equipment must be replaced, once monitoring shows the user's required life has been reached. Repair of fatigue damage is not permissible and damage tolerance is not essential.

A7.5.2 Unmonitored Safe Life

If inspection and monitoring use of an equipment or component is impractical or is not accepted by user, it is necessary to ensure safety from possible catastrophic failure, by increasing the user's required life by a factor of ten ($10n$). This also covers variation in the load spectrum during the life of the equipment. Although the user is absolved from checking usage of the equipment, only the life requirement of n is guaranteed. This does not automatically mean a longer life. If the load spectrum is going to be unchanged through the service life, $6.7n$ may be used. The stress range due to the fatigue design load range, P_{EAT} will not exceed the stress range from most suitable minimum curve for S/N at $15n$ ($1.5 \times 10n$) or from the most suitable mean curve at $22.5n$ ($1.5^2 \times 10n$). If the load spectrum will be unchanged, the stress range at $10.0n$ with a minimum curve or at $15.75n$ with a mean curve may be used. In addition, a check must be made to ensure that the stress due to the design load, P, does not exceed the lower value of the allowable stress from Section A6.

A7.5.3 Infinite Life

This is generally recognised as designing to the asymptotic stress from the most suitable minimum curve for S/N which is taken as that at $n = 1 \times 10^7$ cycles for steels or 2×10^6 cycles for aluminum alloys; or the static safety coefficient of 1.33 (section A6.3.1) can be applied to the stress from the mean curve for material at these cycles. Stress levels must be checked by test, and a confirmatory fatigue test is desirable. Infnite life is rarely used, as unmonitored safe life normally satisfies the user's requirement.

A7.5.4 Fracture Mechanics

Application of fracture mechanics is recommended by assuming an undetected initial crack at the most unfavourable place (e.g., lug, bolt) of critical component. This crack must not exceed the critical crack size during a design life to be defined. Otherwise, a change in design, material, or inspection is necessary giving a damage-tolerant design. If this is not possible field inspection is required giving monitored safe usage life design.

A8 – TESTING

A8.1 GENERAL

Testing must be undertaken in order to confirm that equipment satisfies the requirements of the user and this Code and to validate the design. Testing should identify all critical features and failure modes. Testing should also cover environmental effects on equipment use, in storage and life, especially if degradation is possible. Accelerated testing should be relatable to actual life. Crossing equipment may not be a single structure but a complex assembly and the checking of performance must relate to the compatibility of the equipment as a system. The following tests are considered; requirement test, structural strength test (static), trafficking, additional tests

for floating equipment, fatigue (dynamic), and test during production. Troop trials are not covered.

A8.2 USER TRIALS/PERFORMANCE TESTS

Equipment must pass the relevant tests and then be approved by the user, through user trials/performance tests, before acceptance into service.

A8.3 DUAL TESTING

It is preferred that structural strength tests are carried out first on one equipment, and then concurrently trafficking and the fatigue test are carried out in parallel as considered necessary.

A8.4 REQUIREMENT TESTS

Complete systems and components must be tested to show that the user requirements and the relevant design parameters in this Code are met. Testing will include construction, launching, recovery and transport. It must be shown as far as possible that equipment will perform satisfactorily in field-service conditions and that equipment can be stored and used in the required environmental conditions.

A8.5 STRUCTURAL STRENGTH TESTS

A8.5.1 Equipment and components must be tested to show that there is at least the safety margin required by this Code between the working load, *P,* and the onset of unacceptable permanent distortion in the structure, and that no unforeseen structural behavior occurs. This is achieved by the overload test. It is essential that an overload test is carried out on complete structures. It also should be shown that allowable stresses are not exceeded at the working load, *P,* in areas free from stress concentrations. It will generally be necessary to carry out vertical and transverse loading tests. It is desirable that an ultimate load test is carried out on critical components and preferably on complete structures.

A8.5.2 The test load used will be the most severe combination of loads for which the components or structure has been designed. Test

loads should be applied in such a manner that local effects and deflections produced by the actual loads in use are reproduced as closely as possible. The applied test loads and the structure should be given, as far as possible, the same degree of freedom as actually occur in the field in order to minimise spurious restraining loads that would otherwise be induced as the structure deflects and rotates.

A8.5.3 If it is impractical to reproduce all the applied loads, the required effect may be produced by simulated loads or by increasing the value of other loads, providing this does not affect the validity of the results.

A8.5.4 If a load on different axis produced 5 per cent or less of the total effect, being examined and is difficult or expensive to apply, it can be omitted provided stability is not affected and the omission is stated and allowed for in the test report.

A8.5.5 A structure or component under test must be supported so that accurate measurements of strain deflection, and permanent set can be made.

A8.5.6 The effect of actual in-service bearing and support conditions must be covered in other tests. Components also must be supported as they would be in the complete structure.

A8.5.7 The structure or component must be tested at the most disadvantageous, in-service geometric conditions allowed in design.

A8.5.8 In addition, it may be considered desirable to check that a structure can accept, with a lower factor of safety, more extreme geometric or loading conditions than are allowed in design if occasional specific misuse in-service can be envisaged.

A8.5.9 Working Load Test

A8.5.9.1 This may be a separate test or may be allowed tocontinue into the overload test.

A8.5.9.2 The critical value of the design load, *P*, defined in Sections A5 and A6, will be applied to the structure. The load should be applied in sufficient number of increments and decrements to determine that the structure is behaving in linear elastic manner.

A8.5.9.3 Each increment of load will be held for 2 minutes, after which measurements of deflection and strain will be recorded.

A8.5.9.4 Net stresses are not to exceed the allowable working values given in this Code. If repeated applications of the load are required, stresses shall be consistent among applications.

A8.5.9.5 Once the structure has settled down, there shall be no permanent set on pinholes or deflections because of further application of the design load, *P*.

A8.5.9.6 The structure will be examined before proceeding to the overload test to confirm to the designer that there is no unacceptable cracking, loosening, or pulling of mechanical fasteners; structural deformation; or other signs of damage. The structure should be within dimensional tolerances.

A8.5.10 Overload Test

A8.5.10.1 The test overload, *O,* will be critical values of the design load, *P,* from Sections A5 and A6 multiplied by the safety factor 1.33. The load, *O,* will be applied a minimum of 3 times.

A8.5.10.2 Before proceeding to the overload test, the structure should be loaded once to working load, *P,* and unloaded before setting instrumentations to zero readings. This procedure is intended to settle supports, joints, and the loading distributing system. It may be omitted if the overload test has been immediately preceded by the working load test.

A8.5.10.3 The first load application will be in increments. Each increment of load will be held a for minimum of 2 minutes, after which measurements of deflection and strain will be recorded. Each application of the test overload, *O,* will be held for 30 minutes.

A8.5.10.4 The overload, *O,* will be removed, intermediate readings during off-loading will be taken if required, and residual measurements of deflection and strain will recorded. A recovery period may be allowed if considered necessary, and the residual measurements will be taken again. The load may be taken off at any stage if a check on the onset of permanent

set is required. Elastic buckling with no critical secondary effects is acceptable.

A8.5.10.5 The structure will be examined to confirm to the designer that there is no unacceptable cracking, loosening, or pulling of mechanical fasteners; structural deformations; or other signs of damage.

A8.5.10.6 The test overload, *O,* then shall be applied without increments, up to an additional two times or until linearity and repeatability has been demonstrated.

A8.5.10.7 The last application of the overload, *O*, should be made in increments, and the overload, *O*, should be held for 30 minutes. Residual measurements of strain and deflection shall be recorded after the structure is completely unloaded, and these shall be used to assess any evidence of damage.

A8.5.10.8 The structure or component will have passed the test, if it passes the conditions of Section A8.5.10.5 and if there is no permanant set exceeding the allowable limits given in Section A8.5.10.9.

A8.5.10.9 The aim of the test is to demonstrate repeatability and to assure that there is no permanent set due to the last application of the overload, *O*. To ensure a safe structure or component, it is also necessary to limit the permanent set due to the first application of the test overload, *O*. Theoretically, there may be up to approximately 0.2% permanent set on the first load application and none after a few load applications. There will be some settling of connections. Some permanent set can be allowed provided this does not cause subsequent problems. See Allowable Permanent Set table.

A8.5.10.10 If a component or structure does not satisfy the permanent set limits for the first application of the test overload, it must then be shown that it can take at least the ultimate load, *U*, after allowing for dimensions and material values.

A8.5.10.11 If a structure or component shows no or very little permanent set, the test overload, *O,* may be increased to establish a higher rating and satisfy Section A9.

Allowable Permanent Set

Deflections	On first application of test overload O*	Due to the last, application of test overload O*
1. Connections, pinholes, pins where local yielding, bearing, and settlement can occur.	0.4 per cent	0.2 per cent
2. Deflections	0.2 per cent	0.1 per cent
3. Deflections which are a summation of permanent sets.	0.4 per cent	0.2 per cent

Permanent buckling due to the last application of the test overload is not acceptable in a compression member that has no alternative load paths.
Items 1 and 2 need not be checked if the requirements of Item 3 are met. However, other specification requirements for a particular equipment may necessitate the checking of Items 1 and 2.
These dimensional changes are the result of external load effects. Ensure that thermal effects are allowed for separately.
*Percentages are expressed in relation to maximum deflection for deflections.

A8.5.11 A component or structure can be modified or repaired at any stage during the structural-strength testing, but it must pass the complete overload test in its final form.

A8.5.12 Ultimate Load Test

A8.5.12.1 The ultimate load capacity for an equipment or structure or component should be established but is not mandatory.

A8.5.12.2 The load, U, will generally be established by increasing the load at the critical position without the other applied loads and with level bank-seat supports. The designer must establish the critical components and load position considering transverse and longitudinal effects and combination of bending and shear. The amount of vehicle eccentricity and inclined support effect to be applied must be carefully considered.

A8.5.12.3 The ultimate load U, is the maximum load. The calculated ultimate load, U_C, will be the critical values of the design load, P, from Section V, Loads and Load Combinations, and Section VI, Safety, and multiplied by the safety factor 1.5.

A8.5.12.4 For an equipment or structure the limit of use may occur before the ultimate load, *U,* is reached due to distortion. The load limit when an equipment or component is recoverable and/or cannot be reassembled is of interest, but may not be the ultimate load, *U*. Failure of a structure has not been reached when individual components fail which do not cause failures of the whole structure or stop it being used.

A8.5.12.5 The load shall be applied in regular increments no greater than the increments used in the overload test. Each increment of load should be held for five minutes after which measurements of strain and deflection will be recorded. The load at which permanent set becomes unacceptable must be established if not already covered by the overload test. The structure must be carefully examined for any signs of incipient failure due, for example, to buckling or weld tearing that may not be obvious from the readings being taken. The calculated ultimate load, U_c, should be held for 30 minutes. It is expected that this load will be exceeded. If the ultimate load capacity is required to be established, then the calculated ultimate load, U_c, is strictly an acceptance condition in that it must not be less than the requirements of section A6.3.1. Failure may not be in the expected mode so careful observation is required. This may be aided by loading under displacement control.

A8.5.12.6 The ultimate load capacity from the test is not representative for the whole population because of the variability of the material tested, the geometrical variability, dimensions of failed sections, residual fabrication stresses), and the limited sample.

A8.6 TRAFFICKING TESTS

A8.6.1 To demonstrate that vehicles have no difficulty in crossing the bridge and that no oscillations or deflections occur that could cause damage or limit crossing, the tests will be conducted

wherein a number of vehicles likely to use the bridge will cross on both directions at varying speeds up to the maximum possible as defined in section A4.2.10. These tests should be used to establish the working-stress data caused by impact and eccentricity. Crossings also will be made at the extreme longitudinal and transverse slopes allowed with mud and, if possible, snow and ice on the deck. These tests shall be carried out on a representative bank seat conditions at minimum and maximum spans.

A8.6.2 Deck-wear tests will be carried out to show that the deck system will have an acceptable life span. The vehicles should include most aggressive tracks as well as the most common crossing vehicles. Gravel and stones shall be placed on the deck in order to check for puncturing.

A8.7 ADDITIONAL FLOATING EQUIPMENT TESTS

A8.7.1 Requirement tests for floating bridges and rafts will include stability and flotation. A raft must be tested to show that it is stable when steered in all directions - in the maximum current if possible - and that control is not lost when it rotates. Clear-span parts, joints, connections, and, as far as possible, the structure and components should be given an overload test. After the test overload, *O,* slight buckling of the pontoon skin is acceptable providing it remains watertight and usable. There are, however, two major problems in testing floating equipment: (i) flotation may not be sufficient to carry the test overload, and (ii) it may not be possible to cover the range of hydrodynamic conditions.

A8.7.2 A load test will be carried out in still water to the limit where there is no freeboard. If safety permits, the test may be carried further, but it should not exceed the overload test condition.

A8.7.3 At least one full system test will be carried out with hydrodynamic conditions as near as possible to the most severe or critical.

A8.7.4 A stability test is performed to determine the floating structure's righting moment for roll angles up to the point where capsizing is imminent. Tests should be run for both loaded and unloaded conditions in still and fast water. The laden weight and centre of gravity (CG) must be established by relating the loads and their positions to the unladen conditions determined first. Heel angles should be increased by approximately 2.0 ° increments until the heeling force (usually applied by pairs of cables that do not affect buoyancy), drops off sharply. This indicates the approaching instability/ capsizing, and the test is stopped. For a structure with adequate stability, the heeling may be limited at the discretion of the designer.

A8.8 FATIGUE TESTS

A8.8.1 At least one complete bridge should be tested by trafficking with a range of vehicles which are representative of those that will use the bridge and produce the fatigue design loading conditions. Decking and cross-girders could require wheel or axle loadings which are not given by a tracked vehicle. Trafficking is necessary because it is not normally possible to reproduce in the laboratory all of the conditions caused by a rolling load and the interaction of bridge components at all locations or vibration loading.

A8.8.2 The trafficking test should be carried out over the range of vehicle speeds that will occur in service for at least a total of n cycles or crossings and desirable up to $1.5n$. Impact and eccentricity will occur naturally. A field trial is the only comprehensive test covering all possible fatigue critical areas and all loading arising from the crossing vehicle. A test in the laboratory requires the engineer to identify the fatigue critical area(s).

A8.8.3 If the test is continued in the laboratory, actual stresses measured at particular location as the bridge is crossed should be reproduced instead of the fatigue design load range P_{FAT} .

Laboratory testing must load the fatigue critical areas, and tests at several load positions may be necessary to cover different details and/or bending and shear. Due to the symmetry of structure about its major axes and the repeated details along the length, there will be two or more fatigue critical details sample. It may be possible to increase the number of samples tested by adjusting the position, contact area, and magnitude of the load so that the samples are all correctly loaded, provided transverse loading due to differential deflection is not critical. All detail considered part of a sample must be justified by the measurement of strain or load distribution or accurate detailed analysis.

A8.8.4 Sample Testing

A8.8.4.1 It is normally not possible to test more than one or two complete structures and, because there can be considerable differences in performance of nominally identical structure when subjected to the same fatigue loading; there is still a risk that the worst structure will have a life less than the design life.

A8.8.4.2 The fatigue test load shall be applied to the structure for at least the design life 1.5*n* without repairs or replacements being necessary. The test must also be continued to determine the eventual mode of failure and so that cracking and inspection techniques can be confirmed or alternatives prescribed to ensure damage tolerance. The test life required for the number of equally stressed samples being tested is obtained by factoring *n* using the following table for military bridges allowing 95 per cent confidence of 95 per cent exceedence. The accepted value of σ used is log 0.176.

(Note: Sample (for fatigue testing)- For large components and in order to increase the number of samples tested, it may be possible to consider that there is more than one sample of the fatigue critical detail, providing the geometry and loading are identical and the onset of cracking of one sample does not influence the loading of any other sample. Symmetry of a structure and repetitive details along a structure can be considered, providing the loading is symmetrical).

Number of samples tested	**1**	**2**	**4**	**6**	**8**	**9**	**10**	**100**
All samples failed, factors *n* log mean assuming population Standard deviation log 0.176	3.80	3.12	2.72	2.56	2.47	2.43	2.41	2.08
First sample to fail with population standard deviation assumed as log 0.176	3.80	2.65	2.00	1.75	1.60	1.54	1.50	0.91

A8.8.4.3 In fatigue test of bridges, usually a set of identical component stressed very similarly is present. So, several samples are tested. When one sample fails, the second line of the table applies.

A8.8.4.4 If the bridge lasts for the factored number of cycles, it is considered to have met the life requirement. When failure occurs at a life between 1.5*n* and the factored number of cycles, the designer must show that the structure is a worse-than-average sample and that there is not design or production fault. An example would be if the bridge stresses at the location of failure agree in detail with design stresses and if the specimen adequately represents in detail the bridge in material, geometry, and fabrication technique.

A8.8.4.5 Alternatively, a minimum life can be calculated from first principles using test results of components or structures using a test factor derived by a method such as shown in DOT/FAA/AR-MMPDS-01, Chapter 9. This must take into account; the upper limit of exceedance and the degree of confidence, and the number of samples and variations allowed compared with the final production population (for e.g., different batches of material from different suppliers, different manufacturing equipment, different operators, different factories, and changes with time).

A8.8.5 During the trafficking and laboratory tests, regular inspections must be carried out including those proposed for use in service. Cracks should be allowed to grow and be monitored to investigate:

- Possible variations in crack growth rate
- Frequency of in-service inspections

- Cracks becoming detectable soon after an in-service inspection
- The effect of non-detection of a crack at an in-service inspection

This information should be used to establish the final form and frequency of in-service inspections and to assess remaining working life.

A8.8.6 At all times during the tests, the structure must be capable of withstanding the fatigue design load range, $P_{EAT,}$ increased to an equivalent of maximum working load, P, for the fatigue critical section without collapse. This should be confirmed at regular intervals and at the end of the test. If periodic application of high load improves the fatigue life, allowances may have to be made for this effect.

A8.8.7 At no time before or during the fatigue tests should loads higher than the maximum working load P be applied to a component or structure unless it forms part of the specified acceptance or in-service proving procedure, in which case it should be included in the test. Any overloading beneficial to fatigue life must be disclosed.

A8.8.8 Cracks that are practical and economical to repair may be repaired before they endanger the structure or other components by deformation or collapse, providing the repair can be carried out during service. Similarly, components may be replaced if practical and economical. Uneconomical repairs or replacements may be made during a test to prove other parts of an equipment.

A8.8.9 If there are changes between prototype and production that could reduce the fatigue life or transfer failure elsewhere, early production equipment or components must be tested to establish that the life requirement is still satisfied.

A8.8.10 Equipment designed for safe life must be tested to show that the required life multiplied by the appropriate factors from the table given in Section A8.8.4, is satisfied. The test may also be continued to 1.5n for monitored usage, 6.7n for unmonitored constant load spectrum and 10n for unmonitored usage

multiplied by the appropriate factor from the table given in Section A8.8.4 to show the design assumptions have been achieved. The inspection requirement (Section A8.8.5) and in-service repairs (Section A8.8.8) are not applicable, but still may be used in case the structure fails to meet these life requirements and is accepted as damage tolerant.

A8.9 RESONANCE

During testing it should be confirmed that the natural frequencies of a bridge, part of a bridge, or component are such that they will not be made to resonate by constructions or use. Similarly, there should be no resonance due to wind or water vortex shedding.

A9 – AVOIDANCE OF OVERWEIGHT DESIGN

A9.1 GENERAL

Minimum weight should be a design aim, but it must be balanced with producing economic, robust equipment that will survive in-service use and misuse. On modular bridging equipment the designer should try to anticipate extension of use during development and increased loadings that could result on certain components.

A9.2 PROTOTYPE STRUCTURE

An early prototype structure should show generally that the working or allowable stresses are reached in the working-load test. Allowances may have to be made for eventual deck wear and increased residual stresses and stress concentration of increasing permanent set when the applied load is increased above the test overload, *O,* and before 1.1 times test overload, *O,* is reached. If permanent set occurs only above this, the structure should be modified and retested, unless there are good structural or economic reasons for accepting the overdesign. The applied test load should be related to actual material

properties, allowing for the minimum if there is variation in the different sections used in the structure:

$$P_{TEST} = P\left(\frac{f_t(\text{Material in test})}{f_t(\text{Material Specification})}\right)$$

A9.3 FATIGUE CONSIDERATIONS

If fatigue governs design, the working stresses may be reduced, and the structural strength tests will not be critical. Nonetheless, the designer must check stresses in the structure at this stage. The fatigue test is difficult to use to show overdesign because of scatter of test results and the expense of running further tests. Component or detail laboratory testing should be used with the correct loading as far as possible. Longer life than the requirement must be balanced with the economics of possible weight savings and further fatigue testing.

A9.4 ECONOMIC CONSIDERATIONS

Should tests show the structure to be overdesigned, changes should be made only if it is economical to do so and if it is certain that the changes will not jeopardize the durability, ease of assembly, and other characteristics established as satisfactory on user or other trials.

A9.5 MODIFICATION

It should be noted that it is generally easier to reinforce a structure or component than it is to reduce weight.

A10 – ADDITIONAL CONSIDERATIONS FOR COMPOSITE STRUCTURES

A10.1 GENERAL

The following must be considered:

A10.1.1 Design verification should include following additional failure effects relating to laminate behavior such as interlaminar shear and edge effects.

A10.1.2 Temperature Effects: Normally, a composite would not be selected which would be significantly affected by temperature over the range of working temperatures. If this cannot be achieved, tests must be carried out in the most disadvantageous conditions that could be experienced. Weapon effects must be considered. Thermal stresses in hybrid structures with different moduli of elasticity and/or coefficients of thermal expansion must be considered. Temperature cycling effects are to be considered.

A10.1.3 Surface damage due to roller, wheels, tracks or stones.

A10.1.4 General and local impact damage due to severe mishandling which can cause interlaminar cracks not seen by the eye.

A10.1.5 Environmental degradation particularly due to moisture absorption and ultraviolet degradation.

A10.1.6 The possible effects of galvanic corrosion and thermal cycling for hybrid structures constructed of metals and composite materials.

A10.1.7 Fatigue life, even if the basic material has an asymptotic stress on the stress/number of cycles (S/N) curve, stress concentration, and joints must be investigated. Carbon composites have a good fatigue life when loaded axially in tension; however, when the matrix contribution to load resistance is significant, fatigue lives are only comparable with that of metals. Under cyclic loading, composites are less sensitive to notches than metals. In static loading, they are more sensitive to notches than metals. Fatigue failure should be defined in terms of loss of stiffness as well as onset of cracking.

A10.1.8 Toxicity and flammability during fabrication and in-service use.

A10.2 TESTING

A10.2.1 Structures and components should undergo sustained loading to ensure that the full working load without impact can be maintained for at least 12 hours without unacceptable creep.

A10.2.2 For the overload test (section A8.5.10) the overload factor should be increased to 1.5 to ensure that there is an adequate reserve on the calculated ultimate load, U_C, since there is unlikely to be noticeable yielding or non-linearity.

A10.2.3 Where components include metal joints or parts, it must be decided whether some deformation is acceptable between 1.33*P* and 1.5*P*. Yielding and some deformation is accepted in areas not in contact with composite material.

A11 – RELIABILITY, AVAILABILITY AND MAINTAINABILITY

A11.1 GENERAL

This Code is largely concerned with structural design and its validation. Reliability, availability, and maintainability (RAM) must also be considered to ensure that equipment is capable of repeated transportation, erection, use, dismantling, and reuse under field conditions, and that it can be easily repaired. Structural design and fatigue testing are performed to high levels of exceedance and confidence. The same can be expected of component/system mechanical reliability. When reliability is established by carrying out a number of complete mission cycles/battlefield days, it may be necessary, especially for hand-erected equipment to accept lower levels of reliability and confidence. Reliability trials only can be carried out by troops. There is no relaxation for the number of samples tested except that it can increase the mean-time-between-failure. RAM must be included in trade-off analyses, especially those concerning cost and weight, since it is more cost effective to design in RAM rather than to perform design changes after the equipment is built (see DOD Directive 5000.40, MIL-STD-785B and MIL-STD-721C).

A11.2 FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)

A failure modes, effects, and criticality analysis (FMECA) must be performed for all equipment down to the lowest repairable level early in the design effort. This analysis will be used to identify areas requiring design emphasis to eliminate

modes of failure, to incorporate changes to lessen the effects of certain failures, and to provide a basic maintenance strategy for both corrective repair actions and scheduled inspection, which may be required.

A11.3 PARTS CONTROL AND COMPONENT TESTING

A parts control program will be established to aide in the selection of proven or established parts. The programme will encompass, as a minimum, the hydraulic, electronic/electrical, and mechanical parts used to control and launch/recover the bridge structure. The structural interface of components, linkages, and pins should be selected with the aid of stress-strength analyses. If a fracture control plan, as mentioned in sections A7.4.3 and A7.5.4, is established, it then should become part of RAM. For parts with an unknown reliability database or newly designed parts, component testing should be performed to verify their acceptability for use in military bridging equipment.

A11.4 STRESS DERATING

Criteria for the derating of both electronic and non-electronic parts should be established at the start of new design.

A11.5 DESIGN GUIDELINES AND REVIEWS

RAM design code must be established to assist the designers in achieving the user's requirements. All RAM related efforts should be presented at scheduled design reviews with separate RAM reviews held when deemed necessary.

A11.6 MODELS AND PREDICTIONS

Reliability and maintainability math models should be initiated at the start of a program which represent the functional design as it matures. Predictions should be periodically performed based on the models and FMECA to assess the equipment's capability to meet the user's requirements. Corrective action will be instituted at the onset of noncompliance with these requirements.

A11.7 SOFTWARE DEVELOPMENT

Any software developed for use in automatically controlling bridging equipment must be performed in accordance with an established software quality assurance program. The software should be tested separately before integration with the system hardware.

A11.8 MAINTENANCE CONCEPT

The design effort must be cognizant of the user's maintenance concept to develop equipment maintainable with the expected skill of user personnel, to facilitate the ease of maintenance, and to limit the use of special tools or maintenance test equipment.

A11.9 DESIRABLE MEASURES OF RELIABILITY AND MAINTAINABILITY

A11.9.1 Reliability

The mission reliability should be specified as the mean number of mission cycles before failure which aborts or prevents completion of the missions. The basic reliability should be specified as the mean number of mission cycles before failure which requires corrective maintenance action.

A11.9.2 Maintainability

The equipment maintainability should be specified as a maintenance ratio of maintenance man-hours per mission. The man-hours for both corrective and preventive maintenance should be included in the ratio. An alternative or additional measure would specify a mean time to repair for corrective maintenance actions and preventive maintenance schedule.

A11.9.3 Availability

The measure which should be used is operational availability. This term not only includes operating time and maintenance actions, but accounts for standby time (operable but not in use) and administrative and logistics delays incurred during the repair of the equipment.

A12 – BRIDGE CROSSING RATING

A12.1 GENERAL

This system can be used to increase the load class and/or span under restricted crossing conditions.

A12.2 NORMAL CROSSING

A normal crossing is unrestricted use of an equipment within the parameters of these Guidelines.

A12.3 CAUTION CROSSING

A12.3.1 A Caution Crossing allows, with the same safety as normal crossing, to cross with heavier vehicles or with longer spans by adapting use conditions.

A12.3.2 Regarding bridge crossings, the vehicles must be driven along the centerline of the way. They are guided and their speed must not exceed 5 km/h (3.1 mph). Braking, accelerating and changing gears are forbidden.

A12.3.3 Regarding fixed bridges, vehicles are only allowed to cross one at a time on each independent structural span.

A12.3.4 Regarding floating bridges, several vehicles are allowed to cross only with a distance between vehicles greater than the one established during the conception of the bridge. This value (which must never be lower than 30.5 m (100 ft)) will not appear on the bridge but in the technical documents put at the disposal of the engineer in charge of the bridge.

A12.3.5 Regarding ferries and rafts, the vehicles must be loaded at low speed and guided. They are set up in order to respect the safety and buoyancy of the system. The vehicles' brakes are set and the tires are blocked. Otherwise, it is necessary to avoid any maneuvers of the ferry or raft that would cause swirls and brusque changes of direction.

A12.3.6 For analytical classifications at this crossing level, the same loading and safety factor requirements for normal crossings apply except that impact factor is not required.

A12.3.7 Additionally, to reflect vehicles driving along the bridge centerline, outside girders and trusses may be assumed to carry a minimum of 1/2 the live load. Load distribution will not change for multi-girder bridges.

A12.4 RISK CROSSING

A Risk Crossing allows trafficking with heavier vehicles or with longer spans or with higher current speeds than a Caution Crossing by adapting all the safety factors.

A12.4.1 Regarding bridges, the vehicles cross one by one per span which is structurally independent. They must be driven along the centerline of the way. They are guided and their speed must not exceed 5 km/h (3.1 mph). Braking, accelerating and changing gears are forbidden.

A12.4.2 Regarding ferries and rafts, the vehicles must be loaded at low speed and guided. They are set up in order to respect the safety and buoyancy of the system. The vehicles' brakes are set and the tires are blocked. Otherwise, it is necessary to avoid any maneuvers of the ferry or raft that would cause swirls and brusque changes of direction.

A12.4.3 For analytical classifications at this crossing level, use all of the same assumptions as for Caution Crossing, except the safety factors are lowered to minimum acceptable values.

A12.4.4 Note that low safety factors often mean that the probability of bridge failure is greatly increased and even if failure does not occur, permanent damage to the structure may occur. Structural stresses may be equal to or slightly exceed yield limits, but not exceed ultimate limits. For floating equipments, the probability of sinkage or capsizing is also greatly increased.

A12.5 TESTING

Tests should be carried out with the actual Military Load Class (MLC) vehicle footprint and/or increased spans. Permitted support conditions and secondary loading must be rigorously applied.

ANNEXURE - AA

METAL DATA SHEETS

AA.1 Data sheets of common military bridging materials are provided for information purposes only and are not intended for design. Other materials may also be considered.

AA.2 NOMENCLATURE

AA.2.1 Relative Fabrication and Corrosion Codes

The following comparison codes are used:

a - Excellent
b - Good
c - Fair
d - Poor
X - Not applicable
a-b - Denotes declining rating with higher tempers
b-a - Denotes improving rating with higher tempers

Note: A plus sign following the rating means *better than*
A minus sign following the rating means *not as good as*

The above comparison code definitions are given in *Aluminium standards and data*, Table 3.3, Comparative Characteristics and Applications. Aluminum standards and data is published biennially by The Aluminum Association Inc., 818 Connecticut Ave., N.W. Washington D.C. 20006.

AA.2.2 Symbols

E – Elongation in per cent
L – Longitudinal, rolling, or extrusion direction
T – Long transverse direction
σ_{bru} – Ultimate bearing stress

σ_{bry} – Yield bearing stress

σ_{cy} – Yield compressive stress

σ_{su} – Ultimate shear stress

σ_{sy} – Yield shear stress

R_m – Ultimate tensile stress

$R_{p0.2}$ – Yield tensile stress

σ_{uw} – Ultimate weld strength

σ_{yw} – Yield weld strength

AA.3 INDEX OF METALS

METAL DATA CHART

Material	National designation	Country of origin	Yield stress (N/mm^3)	Ultimate stress (N/mm^2)	Weldability (per cent)	Elongation
Aluminium	2219	U S	250-360	370-440	3-6	Yes
	DGFVE 232B	UK	349-368	408-424	11.3-13.2	Yes
	MVEE 1318B	UK	315-425	385-465	6-8	Yes
	7005	U S	260-310	325-350	7-10	Yes
	AlZn4.5Mg1F35	FRG	140-290	220-350	7-12	Yes
	AlZn4.5Mg2F41	FRG	220-280	320-360	10-12	Yes
	x 7046	U S	117-375	180-420	13-18	Yes
	7075	U S	145-490	275-558	4-10	No
	7020	UK	270	320	8	Yes
	7050	U S	365-483	427-545	3-10	Yes
Steel	S355j2G3	FRG	315-355	480-630	20-22	Yes
	T-1 A514	U S	630-700	730-800	17-18	Yes
	18 % Maraging	US/UK	1,400	1,460	4-15	Yes
	4340	U S	482-1,480	760-1,800	10-22	No

Aluminium

Application: Missiles and space vehicles, pressure tanks, high-temperature applications.

Designation: 2219

Country: US

Availability:
Sheet: *T*31, *T*37, *T*62, *T*81, *T*87
Plate: *T*35, *T*34, *T*62, *T*85, *T*87
Shapes (Ext.): *T*35, *T*62, *T*8511
Tube : *T*31, *T*81
Bar : *T*351, *T*851
Forgings : *T*35, *T*6, *T*851, *T*87

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *b*
Cold Working - *T* ..... *X*
Arc Welding ..... *a*
Resistance Welding ..... *a*
Brazing ..... *X*
Machining ..... *a*

Chemical Composition:
Element %
Si ..... 0.20 max
Fe .....0.30 max
Cu 5.8-6.8
Mn 0.20-0.40
Mg .....0.02 max
Zn ..... 0.10 max
V 0.05-0.15
Ti 0.02-0.10
Zr 0.10-0.25
Others, ea ... 0.05 max
Others, Total . 0.15 max
Al ..... Remainder

Properties:*
Density : 2,800 kg/m^3
Spec Gravity: 2.83
Thermal Exp: 22.3×10^{-6}/K
Mod of Elas : 72×10^3 N/mm^2
Mod of Rid: 27.7×10^3 N/mm^2
K_{IC}: 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *d*
Stress Corrosion ..... *a*

National Specifications:
ASTM B 221-90
QQ-A-250/30
AWS A5.10

Joinings:
Rivet alloys 2219
Welding wire 2219
Weld strength (typ.) .....Heat treated after weld
σ_{uw} .....435 N/mm^2
σ_{yw} .....335 N/mm^2
Elong 10%

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp(L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet & Plate	T62	0.50-50	370	250	6	38	310		820	615	
	T81	0.50-6.0	430	320	6	470	350		930	755	
	T851	6.0-50	410	300	5	430	350		930	755	
	T87	0.50- 00	440	360	6	500	370		970	815	
Extrusion	T8511	0.50-75	400	290	6	410					
Forging	T6	≤100	400	280	4						
	T852	≤100	430	340	3						

* Properties of Alloy 2219 have been changed to comply with most recent specifications.

Application: Military bridges

Aluminium

Designation: DGFVE 232B

Country: UK

Availability:
Sheet .....
Available
Plate .....
Available
Shapes (Ext.)... Available
Tube ..... Available
Bar ..... Available
Forgings ..... Available

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *a*
Cold Working - *T* ..... *c*
Arc Welding ..... *a*
Resistance Welding .... *a*
Brazing .....*b*
Machining .....*b*

Chemical Composition:

Element	%
Si	0.2 max
Fe	0.3 max
Cu	0.12-0.16
Mn	0.15-0.35
Mg	1.8-2.2
Cr	0.05 max
Zn	3.7-4.2
Ti	0.1 max
Zr	0.1-0.25
Others, ea	0.15 max
Others, Total	0.15 max
Al	Remainder

Properties:
Density ..... 2,800 kg/m^3
Spec Gravity 2.8
Thermal Exp ..... 23.8×10^{-6} /K
Mod of Elas ..... 71×10^3 N/mm^2
Mod of Rid ..... 27.7×10^3 N/mm^2
K_{IC}..... 40 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *b*
Stress Corrosion ..... *b*

National Specifications:
Specification DGFVE 232.4

Joinings:
Rivet alloys ..... –
Welding wire NG61
Weld strength (typ.) ..... Naturally aged failure in Heat Affected Zone (HAZ)
T_{mw} ..... 310 N/mm^2
T_{yw} ..... 215 N/mm^2
Elong 5%

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Extrusion	TF		424	368	13.2				820	616	124
Plate			408	352	11.3						122
Thick Plate (82-119 mm)			414	349	11.5						
Forging			410	355	12.2						126

Application: Armor plate

Aluminium

Designation: MVEE 1318B

Country: UK

Availability:
Sheet ..... Not Available
Plate .....Available >6.3 mm
Shapes (Ext.)..Available (MVEE 517)
Tube ..... –
Bar ..... –
Forgings ..... Available

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* .....–
Cold Working - *T* .....–
Arc Welding ..... *b*
Resistance Welding ..... *b*
Brazing ..... –
Machining ..... *b*

Chemical Composition:

Element	%
Si	0.3 max
Fe	0.4 max
Cu	0.25 max
Mn	0.1-0.7
Mg	1.7-3.3
Cr	0.25 max
Zn	4.0-6.0
Zr	0.25 max
Others, ea	–
Others, Total	–
Al	Remainder

Properties:
Density ..... 2,800 kg/m^3
Spec Gravity 2.8
Thermal Exp .... 23.8×10^{-6}/K
Mod of Elas ..... 71×10^3 N/mm^2
Mod of Rid ..... 27×10^3 N/mm^2
K_{IC} ..... 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *b*
Stress Corrosion ..... *b*-

National Specifications:
Proprietary alloy

Joinings:
Rivet alloys ..... –
Welding wire NG61
Weld strength (typ.) ..... Welds naturally aged
σ_{uw} ..... 350 N/mm^2
σ_{yw} ..... 290 N/mm^2
Elong ..... 5 %

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Plate		6-<51	430	360	8						
		51-<76	410	340	8						
		>76	410	340	6						
Extrusion	TF	≤6	430	410	8						
		6-100	465	425	8						
Forging	TF		385	315	7						

Application:
Welded structures, military bridges

Designation: **Aluminium**
7005

Country: US

Availability:
Sheet *T*63, *T*6351
Plate *T*63, *T*6351
Shapes (Ext.)... *T*53
Tube .....—
Bar ..... —
Forgings *T*53

Relative Fabrication Rating:
(See paragraph A.2)
Cold Working - *O* ..... *a*
Cold Working - *T* ..... *c*
Arc Welding ..... *a*
Resistance Welding .....*a*
Brazing ..... —
Machining .....*b*

Chemical Composition:
Element %
Si ..... *0.35 max*
Fe ..... *0.40 max*
Cu..... *0.10 max*
Mn..... *0.20-0.70*
Mg..... *1.0-1.8*
Cr..... *0.06-0.20*
Zn..... *4.0-5.0*
Zr..... *0.08-0.20*
Ti..... *0.01-0.06*
Others, ea..... *0.05 max*
Others, Total..... *0.15 max*
Al..... *Remainder*

Properties:
Density..... 2,800 kg/m^3
Spec Gravity..... 2.80
Thermal Exp..... 23.8 x 10^{-6}/K
Mod of Elas..... 71 x 10^3 N/mm^2
Mod of Rid..... 27 x 10^3 N/mm^2
K_{IC}..... 55 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *b*
Stress Corrosion ..... *b*

National Specifications:
ASTM B 221-90

Joinings:
Rivet alloys 1100, 6053-T61
Welding wire 5356, 5039
Weld strength (typ.) ..... Naturally aged
σ_{uw} ..... 300 N/mm^2
σ_{yw} ..... 200 N/mm^2
Elong 9%

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			F_{tu}	F_{ty}	Elong.(%)	F_{cy}	F_{su}	F_{sy}	F_{bru}	F_{bry}	
Extrusion	T53	All	350	310	10	310	190		495	405	
Sheet & Plate	T63	6-75	325	260	7	325	180		480	365	

Application: Military bridges, amphibious vehicles (M2 Beaver)

Aluminium
Designation: *AlZn4.5Mg*1F35, 3 4335, EN AW-7020

Country: FRG

Availability:
Sheet .....Available
Plate ..... Available
Shapes (Ext.). Available
Tube ..... Available
Bar ..... Available
Forgings ..... Available
Wire..... Available

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *a*
Cold Working - *T* .....*c*
Arc Welding ..... *b*
Resistance Welding ..... *b*
Brazing x
Machining ..... *b*

Chemical Composition:

Element	%
Si	0.35 max
Fe	0.40 max
Cu	0.20 max
Mn	0.05-0.50
Mg	1.0-1.4
Cr	0.10-0.35
Zn	4.0-5.0
Zr	0.08-0.20
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
Density ..... 2,770 kg/m^3
Spec Gravity 2.77
Thermal Exp .... 24.1×10^3 N/mm^2
Mod of Elas ..... 70.5×10^3 N/mm^2
Mod of Rid ..... 27.5×10^3 N/mm^2
K_{IC}..... 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General.....*b*
Stress Corrosion.....*b*

National Specifications:
DIN 1725 Part 1
DIN EN-485
VG 95105

Joinings:*
Rivet alloys ..... 3×3556
Welding wire 3548
Weld strength (typ.) .....Heat treated after weld
σ_{uw} ..... 275 N/mm^2
σ_{yw} ..... 216 N/mm^2
Elong ..... –

Form	Temper	Thick-ness	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
		(mm)	R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet &	0	0.4-12.5	220	360	13	110					45
Plate	T4, T451	0.4-12.5	320	210	13	220					92
	T6, T651	0.4-12.5	350	280	13	280					104
	T62,T651	12.5-175	340	260	7	280					98
Shapes	0.71	3.0-30.0	350	290	10	280					105
Tube	0.71	≤ 20	350	290	10	220					105
Bar	0.71	≤ 50	350	280	10	280					100
		50-100		290	10	220					105
		100-250		270	7	290					100
Forging	0.61	≤ 100	350	280	10	280					95
Wire	0.61	≤ 8	350	290	8	280					100

firms are necessary to perform welding work.

Application: Future military bridges, amphibious vehicles*

Aluminium
Designation:
*AlZn4.5Mg*2F41, WL 3.4336

Country: FRG

Availability:
Sheet ..... Available
Plate .....Available
Shapes (Ext.).... –
Tube ..... –
Bar ..... –
Forgings ..... –

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O*..... *a*
Cold Working - *T*.....*d*
Arc Welding.....*b*
Resistance Welding..... *b*
Brazing..... –
Machining..... *a*

Chemical Composition:

Element	%
Si	0.35 max
Fe	0.5 max
Mn	0.1-0.5
Mg	1.5-2.0
Cr	0.1-0.5
Zn	5.5-6.5
Zr	0.1-0.2
Others, ea	—
Others, Total	—
Al	Remainder

Properties:
Density ..... 2,770 kg/m^3
Spec Gravity ... 2.77
Thermal Exp .. 2.41 × 10^3 N/mm^2
Mod of Elas ... 70.5 × 10^3 N/mm^2
Mod of Rid .....27.5 × 10^3 N/mm^2
K_{IC}..... 30 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... b
Stress Corrosion ..... b

National Specifications:
WL 3.4336
VG 95105

Joinings:
Rivet alloys ..... –
Welding wire 3.3548
Weld strength (typ.) ..... Heat treated after weld
σ_{uw} ..... 275 N/mm^2
σ_{yw} ..... 226 N/mm^2
Elong ..... –

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet	0.71	1.0-3.0	375	335	8						120
		3.0-5.0	395	350	8						120
		5.0-30.0	410	350	8						120
Shapes (Extr)	0.71	3.0-50.0	410	350	8						120

* The material will be available in the development phase of the Bridges of the Eighties program. Current research is directed towards: (a) High-strength welding wire, (b) Improvement of corrosion resistance, and (c) Improvement of fatigue properties.

Application: New proposed welded structure

Designation: Aluminium x7046

Country: US

Availability:

Sheet	0, *T*63
Plate	0, *T*63
Shapes (Ext.)...	–
Tube	–
Bar	–
Forgings	–

Relative Fabrication Rating:
(See paragraph BA.2)

Cold Working - *O*	*a*
Cold Working - *T*	*c*
Arc Welding	*a*
Resistance Welding	—
Brazing	*b*
Machining	—

Chemical Composition:

Element	%
Si	0.40 max
Fe	0.35 max
Cu	0.10 max
Mn	0.30 max
Mg	1.3 max
Cr	0.12 max
Zn	7.0 max
Ti	0.03 max
Zr	0.12 max
Others, ea	—
Others, Total	—
Al	Remainder

Properties:

Density	2,800 kg/m^3
Spec Gravity	2.8
Thermal Exp	23.8×10^{-6}/K
Mod of Elas	71×10^3 N/mm^2
Mod of Rid	27×10^3 N/mm^2
K_{IC}.....	–

Corrosion Resistance:
(See paragraph BA.2)

General	a
Stress Corrosion	—

National Specifications:
–

Joinings:

Rivet alloys	—
Welding wire	5183
Weld strength (typ.) ...	—
σ_{uw}	—
σ_{yw}	—
Elong	—

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)*								Brinnell No.
			Tension (L)			Comp (L)	Shear		Bearing		
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet & Plate	0		180	117	18	117					
	T63		420	375	13	375					

*Typical properties.

Application: Aircraft and high-strength nonweldable applications

Aluminium Designation: 7075

Country: US

Availability:
Sheet 0, *T6*, *T73*
Plate 0, *T6*, *T73*
Shapes (Ext.)..0, *T6*, *T73*
Tube 0, *T6*, *T73*
Bar 0, *T6*, *T651*
Forgings 0, *T6*, *T73*

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *a*
Cold Working - *T* ..... *d*
Arc Welding ..... *c*, *d*
Resistance Welding ..... *b*
Brazing ..... *X*
Machining ..... *b*

Chemical Composition:

Element	%
Si	0.40 max
Fe	0.50 max
Cu	1.2-2.0
Mn	0.30 max
Mg	2.1-2.9
Cr	0.18-0.28
Zn	5.1-6.1
Ti	0.20 max
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
Density ..... 2,800 kg/m^3
Spec Gravity 2.8
Thermal Exp ... 23.8×10^{-6}/K
Mod of Elas ..... 71×10^3 N/mm^2
Mod of Rid ..... 27×10^3 N/mm^2
K_{IC}..... 32 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *c*
Stress Corrosion ..... *c*, *b*

National Specifications:
ASTM B209
ASTM B221
ASTM B241

Joinings:
Rivet alloys 6061, 2117, 2017,2024
Welding wire ..... —
Weld strength (typ) .... (Not recommended)
σ_{uw} ..... —
σ_{yw} ..... —
Elong ..... —

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)*								Brinnell No.
			Tension (L)			Comp (L)	Shear		Bearing		
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet & Plate	0	40-50	275	145	10	145	185	68	600	285	60
	T6	1-50	530	460	6	530					
	T73	1-6	460	385	8	385					
Extrusion	0	All	275	165	10	165					
	T6	0.50-50	558	490	7	490					
	T73	1.5-50	470	400	7	400					
Forging	T6	≤ 50	500	420	9(L)/4(T)	420					
	T73	≤ 50	440	370	7(L)/4(T)	370					

Application: Unspecified

Aluminium
Designation: 7020

Country: UK

Availability:

Sheet	Available
Plate	Available
Shapes (Ext.).	Available
Tube	Available
Bar	Available
Forgings	Available

Relative Fabrication Rating:
(See paragraph BA.2)

Cold Working - *O*	*a*
Cold Working - *T*	*c*
Arc Welding	*a*
Resistance Welding	*a*
Brazing	*b*
Machining	*b*

Chemical Composition:

Element	%
Si	0.35 max
Fe	0.40 max
Cu	0.2 max
Mn	0.05-0.5
Mg	1.0-1.4
Cr	0.1-0.35
Zn	4.0-5.0
Zr	0.08-0.2
Ti	0.1 max
Zr + *Ti*	0.08-0.25
Others, ea	–
Others, Total ...	–
Al	Remainder

Properties:

Density	2,800 kg/m^3
Spec Gravity	2.8
Thermal Exp	Expected to be
Mod of Elas	within 5% of
Mod of Rid	values obtained
K_{IC}.....	for Al 7005

Corrosion Resistance:
(See paragraph BA.2)

General	*b*
Stress Corrosion	*b*

National Specifications:
–

Joinings:

Rivet alloys	–
Welding wire	NG61
Weld strength (typ.)	Naturally aged
σ_{uw}	300 N/mm^2
σ_{yw}	200 N/mm^2
Elong	5%

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)*								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet, Plate & Extrusion	TF		320	270	8						

* Above are minimum tensile properties expected from any thickness of any wrought form. Typical values of 12-25 mm (0.5-1.0 in) thick plates or extrusions are likely to be some 50 MPa (7,250 lbs/in^2) above these values.

Application: Military bridges, upgrades

Aluminium Designation: 7050

Country: US

Availability:
Sheet ..... Clad
Plate *T*7651, *T*7451, *T*73651
Shapes (Ext.).. *T*76511, *T*73511
Tube ..... Not Available
Bar ..... Not Available
Forgings *T*7452, *T*74, *T*73652

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* .... *b*
Cold Working - *T* .... *b*
Arc Welding ..... *d*
Resistance Welding... *b*
Brazing ..... *d*
Machining ..... *b*

Chemical Composition:

Element	%
Si	0.12 max
Fe	0.15 max
Cu	2.0-2.6
Mn	0.10 max
Mg	1.9-2.6
Cr	0.04 max
Zn	5.7-6.7
Zr	0.08-0.15
Ti	0.06 max
Others, ea	0.05 max
Others, Total	0.15 max
Al	Remainder

Properties:
Density ..... 2,830 kg/m^3
Spec Gravity ..... —
Thermal Exp ..... 23.0 x 10^{-6}/K
Mod of Elas ..... 70.3 x 10^3 N/mm^2
Mod of Rid ..... 26.9 x 10^3 N/mm^2
K_{IC}..... 45.1 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)
General ..... *c*
Stress Corrosion ... *b*

National Specifications:
AMS 4050A, 4201, 4340, 4342, 4341, 4107, 4108

Joinings:
Rivet alloys 7050-*T*73
Welding wire 5356, 4043
Weld strength (typ) 50% of parent metal
σ_{uw} ..... —
σ_{yw} ..... —
Elong 1%

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)								Brinnell No.
			Tension (L)			Comp(L)	Shear		Bearing		
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Plate	*T*7651	6-76	524-545	455-483	7-9	441-503	290-324		765-1041	600-758	
	*T*7451	6-152	483-524	414-462	4-10	393-483	290-310		724-1027	593-745	
Extrusion	*T*76510	12-127	469-545	407-476	7	455-490	283-303		738-1041	558-765	
	*T*73510	19-127	427-483	365-414	8	393-421	255-269		634-910	510-655	
Forging	All	50-150	455-496	372-427	3-9	393-441	276-290		662-903	538-696	

Application: Bridge structures, general structures

Designation: **Steel** S355J2G3

Country: FRG

Availability:

Sheet	Available
Plate	Available
Shapes (Ext.)..	Available
Tube	Available
Bar	Available
Forgings	Available

Relative Fabrication Rating:
(See paragraph BA.2)

Cold Working - *O*	*a*
Cold Working - *T*	*a*
Arc Welding	*a*
Resistance Welding	*a*
Brazing	*a*
Machining	*a*

Chemical Composition:

Element	%
C	0.20 max
P	0.05 max
S	0.05 max
N	0.04 max
Others, ea	–
Others, Total	–
Fe	Remainder

Properties:

Density	7,850 kg/m^3
Spec Gravity	–
Thermal Exp ..	12.0×10^{-6}/K
Mod of Elas ...	204×10^3 N/mm^2
Mod of Rid	79.5×10^3 N/mm^2
K_{IC}.....	–

Corrosion Resistance:
(See paragraph BA.2)

General	*d*
Stress Corrosion	*a*

National Specifications:
DIN EN 10025

Joinings:

Rivet alloys	S275J2G4
Welding wire	S355
Weld strength (typ.)	No heat treatment
σ_{uw}	490-630 N/mm^2
σ_{yw}	–
Elong	–

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)*								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
All	N	3-16	490	355	22						
		16-40	–	345	22						
		40-63	–	335	21						
		63-80	630	325	20						
		80-100	630	315	20						

* The ratio of strength to density is hardly satisfactory for military bridges. Maraging steels have better values for static strength, but there are difficulties regarding fatigue behavior and ductility.

Application: High-strength, welded construction equipment and machinery

Designation: Steel
T-1 Steel

Country: US

Availability:
Sheet ..... —
Plate .....
Available
Shapes (Ext.)... —
Tube .....
Available
Bar .....
Available
Forgings ..... —

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *a*
Cold Working - *T* ..... *a*
Arc Welding ..... *a*
Resistance Welding ..... *a*
Brazing ..... *a*
Machining ..... *a*

Chemical Composition:

Element	%
C	0.10-0.20
Ni	0.60-1.0
Mo	0.40-0.60
Mn	0.60-1.0
Cr	0.40-0.65
Si	0.20-0.35
V	0.03-0.08
Cu	0.015-0.50
Others, ea	0.04 max
Others, Total ...	1.0 max
Fe	Remainder

Properties:
Density ..... 8,000 kg/m^3
Spec Gravity 8.0
Thermal Exp ..... 13.9 x 10^{-6}/K
Mod of Elas ..... 210 x 10^3 N/mm^2
Mod of Rid ..... —
K_{IC}..... —

Corrosion Resistance:
(See paragraph BA.2)
General ..... *d*
Stress Corrosion .... *a*

National Specifications:
ASTM-A-514

Joinings:
Rivet alloys ..... –
Welding wire ..... Low-hydrogen rod (E120)
Weld strength (typ.) .....Typical
σ_{uw} ..... 730 N/mm^2
σ_{yw} ..... 630 N/mm^2
Elong 11%

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet & Plate		5-64 64-150	800 730	700 630	18 17	700 630	600 550	400 360			321

* Elongations are given for 50.8 mm (2.0 in) gage length.

Application: Aircraft components, mechanism parts

Steel Designation: 18% Maraging

Country: US & UK

Availability:

Sheet	Available
Plate	Available
Shapes (Ext.).	—
Tube	—
Bar	—
Forgings	Available

Relative Fabrication Rating:
(See paragraph BA.2)

Cold Working - *O*	*a*
Cold Working - *T*	*X*
Arc Welding	*a*
Resistance Welding...	*a*
Brazing	—
Machining	*d*

Chemical Composition:

Element	%
C	0.02 max
Ni	18.5 max
Co	8.5 max
Mo	4.8 max
Mn	0.3 max
Ti	0.25 max
Si	0.01 max
Al	0.20 max
Others, ea	0.04 max
Others, Total ...	1.0 max
Fe	Remainder

Properties:

Density	8,000 kg/m^3
Spec Gravity ..	—
Thermal Exp..	10.0 x 10^{-6}/K
Mod of Elas ..	189 x 10^3 N/mm^2
Mod of Rid ...	72.9 x 10^3 N/mm^2
K_{IC}.....	110 MN/m$^{3/2}$

Corrosion Resistance:
(See paragraph BA.2)

General	*d*	*d*
Stress Corrosion	*d*	

National Specifications: —

Joinings:

Rivet alloys	–
Welding wire.....	Same as base metal
Weld strength (typ)	Equal to parent metal after aging 3 hr @48°C (118°F)
σ_{uw}	1,410 N/mm^2
σ_{yw}	1,350 N/mm^2
Elong	10 % or 50 mm

Form	Temper	Thick-ness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
Sheet & Plate		1.5-6	1460	1390	4	1390					43
		6-11	1460	1390	15	1390					43

* Maraging steel is available in higher strengths (up to 2500 N/mm^2, 362×10^3 lbs/in^2) in special orders.
† Elongations are given for a gage length of 4.5 √A where A is the cross-sectional area in square inches.

Application: Pins, hinges, hydraulic pressure vessels, mechanism linkages

Designation: Steel 4340

Country: US

Availability:
Sheet ..... –
Plate ..... Available
Shapes (Ext.).. –
Tube ..... Available
Bar ..... Available
Forgings ..... Available

Relative Fabrication Rating:
(See paragraph BA.2)
Cold Working - *O* ..... *a*
Cold Working - *T* ..... –
Arc Welding ..... *
Resistance Welding ..... *
Brazing ..... *
Machining ..... *a*

Chemical Composition:

Element	%
C	0.38-0.43
Cr	0.70-0.90
Ni	1.65-2.00
P	0.04 max
Mo	0.20-0.30
Mn	0.60-0.85
S	0.15-0.35
Si	0.20-0.35
Others, ea	–
Others, Total	–
Fe	Remainder

Properties:
Density ..... 8,000 kg/m^3
Spec Gravity ... 8.0
Thermal Exp.... –
Mod of Elas .... 200×10^3 N/mm^2
Mod of Rid ..... 76×10^3 N/mm^2
K_{IC}..... –

Corrosion Resistance:
(See paragraph BA.2)
General ..... *d*
Stress Corrosion ... *a*

National Specifications:
ASTM A320/A, 320M-88

Joinings:
Rivet alloys ..... —
Welding wire 4340
Weld strength (typ.) ... Same as parent material after heat treatment.
σ_{uw} ..... –
σ_{yw} ..... –
Elong ..... –

Form	Temper	Thickness (mm)	Minimum Mechanical Properties (N/mm^2)								
			Tension (L)			Comp (L)	Shear		Bearing		Brinnell No.
			R_M	$R_{p0.2}$	E(%)	σ_{cy}	σ_{su}	σ_{sy}	σ_{bru}	σ_{bry}	
All		5-15	1800 760	1480 482	10 22	1650 482	1070				510 290

* 4340 can be welded only with special care.

SLOPE

Slope	Angle (Degrees)	Per cent (%)
1 in 1	45.00	100.00
1 in 2	26.57	50.00
1 in 3	18.43	33.33
1 in 4	14.04	25.00
1 in 5	11.31	20.00
1 in 6	9.46	16.67
1 in 7	8.13	14.29
1 in 8	7.13	12.50
1 in 9	6.34	11.11
1 in 10	5.71	10.00
1 in 11	5.19	9.09
1 in 12	4.76	8.33
1 in 13	4.40	7.69
1 in 14	4.09	7.14
1 in 15	3.81	6.67
1 in 16	3.58	6.25
1 in 17	3.37	5.88
1 in 18	3.18	5.56
1 in 19	3.01	5.26
1 in 20	2.86	5.00

CHAPTER 5

INTEGRATED LOGISTICS SUPPORT

5.1 BACKGROUND

Logistics is a common vocabulary for military systems. Its real meaning and importance, however, is seldom understood. It is therefore essential to appreciate the scope of the entire spectrum of logistics.

In a broader sense, the logistics envelops the entire science of planning and carrying out the movement and maintenance of forces. Logistics is an ongoing 24 h a day function. When the entire life cycle of (say) a bridging system is considered, the resources needed for the logistic support assume more importance than the considerations related only to the initial acquisition cost.

5.2 MAKE OR BUY

When a decision to buy or make a military bridging system is made, the differences between the logistics support methodologies emerge out. In case of buy decision, the supplier (usually an overseas industry) provides the documentation, training, and support requirements. The documentation provided by the manufacturer normally consists of the following:

(a) User handbook

(b) Operation and maintenance manual

(c) Recommended list of spare parts.

As per the standard procedure for introduction of any equipment in India, a separate document entitled as complete

equipment schedule (CES) is issued, which contains the standard list of spares. Working out a list of recommended spares is a highly knowledge-based exercise. The Corps of Electrical and Mechanical Engineers (EME) accomplishes this task at the end of user trials on the indigenously developed equipment for the Army. For imported equipment, the manufacturer's recommendations are normally accepted. In either case, there is much more that needs to be done.

5.3 INDIGENOUS EQUIPMENT

For the indigenous equipment, the anticipated usage of the equipment throughout its life cycle must be known. The environmental conditions such as temperature, humidity, and dust have a major impact on the life of a component. The maintenance schedule and overhaul practices also determine the life and the scaling of spares. The technological changes are quite rapid and if properly followed, can extend the life of a component and the equipment. Considerable experience from field usage and the past performances is available with the corps of EME. Proper maintenance of log books can help create a database, which can be analysed and subsequently used for fault diagnosis. Unfortunately, the importance of this data is not properly understood in the field, especially when a failure takes place. Whenever any malfunctioning of an equipment is noticed in the field, the concerned unit has to raise a defect report which amounts to the basic assumption that the malfunctioning is due to some design defect. The existing procedures of holding courts of inquiry in such cases and the fear that the blame will be attributed to misuse tend to distort the information. The facts are often hidden for the fear of leading to further complex procedures. Such practices have a negative effect on generating a strong and reliable database. The modern industrial quality systems, however, address such issues technically by defining nonconformity in any process which must be captured and solutions found by adopting statistical process control procedures (SPC).

5.4 DEFECT REPORTS

It is often noticed that a new equipment, when used in the field for the first time, encounters certain problems. It could be a failure of

a major system or a component or the equipment may not be giving performance as specified. To cite an example of the former, it may not be possible to launch a bridge due to failure of launching gear during the launch. To cite an example of performance shortfalls, the bridging vehicle itself may not be able to negotiate a slope or a marginal terrain. As per the standard practice with the Indian Army, all such cases will be reported as defect reports and the case histories will be sent to the concerned quality assurance agency. If the defect is of a serious nature, the equipment may be temporarily declared unfit for use to avoid any further damage. The basic assumption behind this methodology is that there is either a design deficiency or a quality problem. Probably, existence of any other reason for such incidents is ruled out. This is a serious shortcoming of the existing procedure.

5.5 FAILURE MECHANISM AND CRITICALITY ANALYSIS

Most people are afraid of the word failure and therefore many incidents which can be termed as failures are pushed under the carpet. However, in any developmental set up, failure is a stepping stone for success. To fail is not a crime; rather coming across a failure gives one an excellent opportunity to learn. Failures should therefore not go unnoticed, neither they should carry any stigma. Reliability studies give high importance to failure mechanism evaluation and criticality analysis (FMEA or FMECA). Such analytical studies try to locate the root cause of the failure through a fault-tree analysis. Once the root cause is located or proper diagnosis is made, remedial measures to prevent such failures in the future are worked out. This can substantially enhance the reliability of the system. Such an approach, if adopted for military systems, and in particular, bridging systems, can lead to a very high degree of reliability, which ultimately will contribute to a total success for the operation.

5.6 MAINTAINABILITY OF IMPORTED EQUIPMENT

Usually, for the imported equipment, the manufacturer's recommendations for operation, maintenance, and repairs are

followed. This is based on the assumption that the equipment has undergone exhaustive testing and evaluation abroad, including reliability studies, and maintainability. For certain systems, where there is no major deviation in the usage pattern, this could prove to be a good practice. However, for equipments like mobile military bridges, the usage pattern could be quite different. For example, the PMP/PMS floating bridge of the erstwhile Soviet block origin, is primarily used for canal crossing in the Indian context; while all the handbooks will assume its primary use for river crossings. This can make a big difference to the wear pattern of the components, and the scaling of spares will have to be accordingly tailored.

For the equipment of foreign origin, planning of procurement of spares is essential. Not only the spares are expensive, but on most occasions, would take a very long lead time. Moreover, with the changes in global and international relationships, some spares are simply not available because the production line with the original manufacturer is closed down. This raises a major problem for substitution and indigenisation. Due to the lack of complete specification (including material specification), it is very difficult to define the requirements document. Even a sample does not serve the purpose. Many efforts and initiatives taken by the maintenance commands and equivalent organisations of the Services to indigenise spares have not produced satisfactory results. Rather than part-by-part replacement, a systems approach could provide effective solutions. A brief case study on the maintainability of the imported MGB would surely bring out that the basic assumptions about the set of the bridge itself would not hold good for the use under the Indian operating conditions. The design input for the basic configuration of the set itself would have given altogether different combinations for the configuration of the set for single-storey and double-storey bridges. Also, while the Indian counterpart for the MGB was developed, a combination of interchangeable components for the Indian and imported version could have been worked out. This would not have only given a cost-effective solution, but would have provided better performance in the indigenous use of the two bridges. Thus, even if our adversary would hold the equipment similar to ours, the effectiveness of our system in the actual field would have been much

better. This goes to prove the point of the importance of logistics in the life cycle of any equipment.

Another issue related to the imported hardware is its optimal utilisation by our troops. The equipment developed abroad (particularly the military bridging equipment) are based on the qualitative requirements pertaining to its country of origin or for generalised global requirements of the theaters of operation that are determined by the military alliances like NATO. India's security perspectives and tactical plans could be poles apart, and accordingly, the operational usage may have to be restricted. Within the foreseeable usage under the regional conditions, the bridging system should have performance not only on par with what the worldwide military equipment has, but also have a superior performance in selected areas where it can give our troops the competitive advantage. This would be possible through trade-off analysis or by adopting quality function deployment methodologies for the design of the indigenous product. Tailor-making of a bridging system for such requirements is possible since the technology base is indigenously available. Development of *Sarvatra* can be cited as an ideal case to demonstrate such an advantage.

Despite all the advantages of the indigenous development, the Army Engineers and the Assault Armoured Regiments will have to continue with equipment of foreign origin for some time to come. In that case, the users normally carry out the exploitation trials on the system and lay down different procedures for usage of the equipment in Indian context. What is often missed out is that the basic configuration of the system is not altered. Perhaps it is considered as an encroachment on the original design if such changes are made or even suggested. Of course, such changes would have to be supported with detailed analytical studies. But the results would be rewarding. Some field commanders would be bold enough to carry out these procedural changes or deviations from laid down procedures. But this will be done without changing the rule book, which will not permit deviating from the standard procedure. Same thing holds good for repair and maintenance procedures. Here again, many indigenous

solutions for repair of welded aluminium alloy components have been found. But these have not been issued as accepted procedures. Such repairs, although routinely carried out in the field, are not documented. Thus, even though considerable innovation is carried out in the field, its content is not structured, and therefore lost in the process. Concurrent engineering approach (discussed in Chapter 7), if followed, would allow the end user to participate in the design and development process. This would result in the formation of multi-organisational team, the specialist members of which could bring important design and life cycle issues upfront.

5.7 INTEGRATED LOGISTICS SUPPORT

It has already been seen that the logistics occupies a major share in the life cycle costing of a military system. From this point alone, it needs to be considered at the design stage itself. When a decision to make is made, it is possible to evolve a logistics-influenced design. The integrated logistics support (ILS), therefore, starts from the logistics support analysis (LSA). The intention of such an analysis is that:

(a) Support considerations are effectively integrated into the system design, and

(b) Required support structure elements are acquired concurrently with the system so that the system would be both supportable and supported when fielded.

Another important factor that influences the life cycle cost is the operation and maintenance costs, generally known as logistics cost. If the total life cycle cost of a bridging system is considered, the various elements could be divided into the following categories:

(a) Research and development costs

(b) Initial acquisition cost

(c) Logistics support cost

(d) Disposal cost

Let it be assumed that the development of a bridging system takes seven years and the expected service life is 20 years for a system.

The system itself could be classified as medium-cost system. For the more expensive systems, there is always an attempt to extend the life for another 10 to 15 years. Thus, this long span of useful life results into a substantial element of logistics support costs. The ILS takes into account all such elements upfront during the design phase itself.

Although in the Indian context, the ILS has not yet become an accepted methodology, the adoption of concurrent engineering as the development philosophy and formation of the maintenance advisory groups (MAG) by EME have been positive initiatives towards meeting the objectives of ILS. It is true that the life cycle analysis has not yet found its rightful place in the system development/acquisition cycle, yet the basic trends and distribution of costs over different phases follows a similar pattern irrespective of the weapon system or the country of origin. Since no elaborate procedures and documentation exists with the Indian Army for fully describing the ILS, it may be worthwhile to have a quick look at the American system, which is well documented.

As per the United States, Department of Defense (DoD), Directive 5000.2 Part 7, Sec A, the ILS has essentially 10 elements. These elements must be addressed both for hardware and software under war and peace conditions. They are the resources required to field and maintain a weapon system in an operationally capable condition. The ILS elements are as follows:

- Maintenance planning
- Manpower and personnel
- Supply support
- Support equipment
- Technical data
- Training and training support
- Computer resources support
- Facilities
- Packaging, handling, storage, and transportation
- Design interface

The DoD directive 5000.2 referred to above gives a detailed explanation to each of the elements listed above. The Indian system of maintenance support through the field workshops and base workshops has been found adequate in the past. However, with the increased complexity of the bridging systems and major changes in participation of private industry, there is a room for rethinking and improvements. No specific improvements are being suggested here; but as a few characteristics are explained in subsequent paragraphs, the basic approach of ILS will become quite clear.

Before some of these elements of the ILS are described, a brief look at the quality expressed in terms of reliability would be worthwhile. Traditionally, the reliability of any system was being measured in terms of the mean time between failure (MTBF) and mean time to repair (MTTR). This concept of mean time is being discarded in case of commercial equipment such as a car or a television set. What is felt by the customer is the variance and not the averages. With this notion about quality, the manufacturer should guarantee the minimum period of a trouble-free service. This period itself is fairly long to assure a long life for the equipment to give trouble-free service. After such a guarantee period, the component may be totally replaced rather than recommend any repairs to it in the field. Such a system is ideally suited for hydraulic or electrical systems where the cartridge or an electronic card can be totally replaced. Apart from giving satisfactory field solution, this method also brings down the skill levels required for carrying out field repairs or maintenance. However, this should not be construed to underestimate the importance of training.

5.7.1 Maintenance Planning

Generally, there are three levels of maintenance: organisational, intermediate, and depot. Organisational level maintenance is the lowest level performed by the unit itself using the equipment. The skills of the people responsible for maintenance at this level is also minimum. Therefore, organisational maintenance is limited to cleaning, replacement of simple parts/components and

identification of those parts which have failed and would need attendance at the next level. Intermediate level maintenance is carried out further away from the user unit where a facility such as a field workshop may exist. The skill levels are also somewhat higher and certain facilities and test equipment are available. Therefore, it is possible to cater for identification and isolation of the defective parts. Such facilities normally provide services for more than one user unit. Depot maintenance is capable of carrying out all repair/maintenance work not within the capability of the intermediate level. The capabilities include overhaul, calibration, and major repairs such as welding of defective structural components. Depot maintenance is normally a fixed facility and caters for a fairly large number of user units. Depot maintenance may be organic (such as provided by the base workshops of EME) or non-organic, where the contractor's facilities will be used for higher level repairs and maintenance. The practice of depending upon non-organic maintenance is still not in vogue with the Indian Army but it cannot be ruled out in future when the weapon systems and equipment are becoming highly specialised and complex and the industry is coming forward for sharing its technology with defence.

Apart from the above organisational structure, building in reliability, availability, and maintainability resulting into dependability is the main theme behind maintenance planning. This is ideally taken care of by the philosophy of ILS.

5.7.2 Manpower and Personnel

For every equipment there is a requirement for certain skills and a certain amount of manpower to operate the system effectively over its lifetime of peacetime and wartime rates. The life cycle analysis process takes into account the issues related to human factors like engineering, manpower, personnel, training, safety, and health hazards. These issues are identified at the concept phase and as the development progresses, these elements become clearer to define and thus can be taken care of during the life cycle analysis process.

5.7.3 Supply Support

Supply support literally means provisioning for a newly introduced system. The Directorate of Standardisation is the appropriate authority under the Ministry of Defence to ensure allotment of part numbers and also to decide proper hierarchy for the same. Although a lot can be done by consolidating the database for standard parts, components, subsystems, and systems used by different arms and services, at present the emphasis is being laid only on commonality and standardisation. Using advanced tools for computer-aided design (CAD) and drafting, it should be possible to develop a product data management (PDM) system that will cut down the inventory size and also speed up the development process. PDM will also enhance the supportability of the system through commonality of the parts and components across the weapon system. PDM is briefly explained in Chapter 7.

5.7.4 Support Equipment

Support equipment consists of the equipment needed to support the operation and maintenance of the system. It includes ground handling equipment, auxiliary power source for independently operating the system without using its prime mover, tools, test equipment, metrology, and calibration equipment. The requirement for the support equipment is to be identified during the development phase itself and its availability is to be ensured when the system is ready for its first operational use.

5.7.5 Technical Data

Technical data, as far as logistics is concerned, consists of the designer's or manufacturer's re corded information to build or test the system. This includes drawings, specifications, operating and maintenance manuals, inspection and test procedures, and calibration instructions. Out of these, the operation and maintenance manuals and user handbooks, etc., must be available when the equipment is being physically tried by the troops in the field. The field trials might necessitate changes and improvements to this documentation.

5.7.6 Training and Training Support

Training and training support element consists of procedures, processes, techniques, training devices, and equipment used to train personnel in the operation, maintenance, and general support of the equipment. In case of weapon systems, ranges are created with specific facilities to cater to training on different weapon systems. For bridging systems, the bridging training camps (BTC) have been created within various operational commands. These camps are normally located near existing canals, rivers or obstacles. However, these cannot cater for all types of obstacles and therefore certain amount of training is accomplished during exercises. Apart from these BTCs, the three centres located at Roorkee, Khadki, and Bangalore and the College of Military Engineering (CME), Dapodi, are also utilised for imparting training and generating useful data for planning and doctrines. The main problem lies with shortage of training equipment and a long gap between introduction of the equipment and making the equipment available for training. Such a situation occurs primarily due to budgetary constraints. The models, both working and crude, are used by the engineering units to train the troops. Such models fall short of simulating the actual field conditions and therefore have a limited utility. The simulators, which can virtually create the battlefield scenarios including visual effects, sounds, etc., are too expensive for being used for training on bridging systems. A compromise solution of a static simulator to acquaint the operating crew of the sequence of operation can provide a satisfactory solution, though short of creating actual battlefield conditions for operating the system against a natural/ man-made obstacle. When more and more indigenously developed equipment reach the users, it would be possible to remove the existing deficiencies, which adversely affect the training needs.

5.7.7 Design Interface

The last and the most important logistics element is the design interface. Design interface is the logistics-related design parameters to readiness and support resource requirements. This is an interactive relationship and iterates throughout the development cycle. The

concurrent engineering approach or the integrated product development is the surest way to capture the logistics-related design requirements in the early phase of the project.

5.8 CONCLUSION

Integrated logistics support is about operational availability where reliability and maintainability as well as logistic support performance are key features of both system availability and system costs. In general, it can be said that logistic support costs make up more than half of the life cycle cost. Traditionally, logistic support has been developed after the development process is complete. Today, a more effective process involves the simultaneous development of hardware and logistic support. Logistic support analysis has two objectives – one is to allow logistic support considerations to influence the design, and second is to develop logistic support resource requirements for the system. It must be remembered that ultimately the availability of any new system and its reliability in the harsh battlefield environment is of utmost importance.

CHAPTER 6

THE BRIDGING EQUIPMENT – WORLDWIDE

There are quite a few sources worldwide which publish catalogues of military equipment under different headings. These are generally classified countrywise and are having a commercial bias. In this monograph, an attempt is made to put available information subjectwise so that developments in a particular field of specialisation can be viewed at a glance.

An attempt was made to get the latest information from many sources in the world. However, the response was mixed. Some readily sent all the pamphlets and specifications and the latest status including the world market trends. For some companies, the information was available on the Web; and some simply did not respond. The author, therefore, has made an attempt to compile the information from all available sources and every attempt has been made to ensure that proper information is included in the monograph. The author also gratefully acknowledges the support given by willing equipment manufacturers and market players who have spontaneously responded to our requests. This Chapter is divided into the following parts:

- Infantry bridges
- World War II equipment
- Armoured vehicle launched bridges
- Ribbon bridge
- Wheeled vehicle-mounted bridges
- Floating bridges and ferries

Tables comparing the performance parameters and the sketches depicting the launch sequences are also included.

6.1 INFANTRY BRIDGES

In the mountain warfare, it becomes necessary for the infantry to cross various obstacles even before the bridgehead is established. The foot soldier has to cross canals, rivers, and other obstacles by swimming, by using inflatable boats, or by ferrying. This has to be followed with continuous reinforcements which include supplies, arms, and ammunitions. Apart from foot soldiers, the RCL guns, and jeeps have also to be taken across.

In the Indian scenario, such a need was strongly felt right from the 1962 operations. The eastern border had a need for such an equipment to be developed and thus came the first indigenously developed bridging equipment, Fixed Bridge MLC 3 shown in Fig. 6.1. All the components of this bridge can be loaded on mules or packed into jeeps. The bridge itself could be quickly constructed in the field by a few men in just 45 min. The design, developed in the seventies was the first major application of weldable aluminium alloy in the country.

In the mid-eighties, the high altitudes became the new battlefields and the problems of obstacle-crossing were altogether different. The bridges or the expedients had to be used to negotiate the crevasses and were required to be man-portable. The carrying capacity of an individual drops down to 10 kg at such altitudes. Moreover, the

Figure 6.1. An exclusive Indian bridge for mountains – fixed bridge MLC 3.

equipment had to withstand subzero temperatures of the order of -40 °C and had to carry ice loads apart from normal dead and live loads. Apart from aluminium alloys, composites have also been tried for such applications.

Not many countries are known to have developed such light weight equipment. However, details about some French and Israeli equipments are available. The Table 6.1 gives the performance parameters of some infantry bridges.

Table 6.1. Typical performance parameters of some infantry bridges

Name of the equipment	Span (m)	Performance
Cl 3 bridge	30	16 men, 45 min
Glacier bridge	10	4 men loads
EWK infantry bridge	30	Launched using floating support

6.2 EVOLUTIONARY DEVELOPMENT OF BRIDGES

World War II saw a major development in military bridging taking place right when the war had broken out, primarily due to unleashing of battle tank which produced dramatic results on the battlefield. Blitzkrieg was the most striking example of this.

The Bailey bridge, which emerged out as the most striking development of the war, set a new benchmark for the operational bridging equipment (Fig 6.2). The development and initial production of Bailey bridges was completed in a record time of one year (1940). During 1941–45, over 5 lakh tonne (or 200 mile) of the bridge was produced by a consortium of 600 British firms.

After the war, Bailey became a common name in many countries which needed many bridges in their infrastructure development. Although, initially thought as temporary bridges, such equipment came to stay for a long period, sometimes exceeding 25 years in service life. The Border Roads Organisation (BRO) set up under the Ministry of Surface Transport, India is one striking example of spin-offs of Bailey bridges to the infrastructure. Yet till the late 1970s, Bailey also provided an excellent solution to the Indian Army's obstacle-crossing problems during the major conflicts in 1965 and 1971.

Figure 6.2. The Bailey bridge provided a universal solution to the obstacle-crossing problems through different variants ranging from a floating bridge to a suspension bridge.

In the post World War II period, the use of Bailey bridge did not remain restricted only to the developing countries, but in the developed world as well, the new variants of Bailey bridging, primarily developed by Mabey and Johnson, UK, demonstrated the effectiveness of the concept when new materials were available. In India, Garden Reach Shipbuilders and Engineers have brought their own variant using better quality steel. The Table 6.2 gives the configurations of some of the bridging equipment.

Table 6.2. Typical configurations of World War II bridges

Name of the equipment	Span
BAILEY, single - single	100 ft
BAILEY, double - double	240 ft
BAILEY, triple - double	350 ft
MABEY, universal	5-215 m
MABEY, highway	30.5 m

6.3 BRIDGES OF COLD WAR

The cold war years kept the two super powers engaged in many developments, right from the weapons of mass destruction (WMD) to a new family of battle tanks with improved firepower, protection, and mobility. This necessitated simultaneous development of higher-performance assault bridges capable of operating in NBC environment and designed for higher and higher payloads. Also, the demands for longer spans and other capabilities to provide crossing means for more difficult obstacles came to the fore. This gave a new face to the entire military bridging equipment especially armoured vehicles launched bridges. Here again, the European countries viz., the UK, France, and Germany, remained as the leaders from the NATO side while the Russians ably supported by the Czechs and the Polish became the competitors from the Warsaw Pact Nations. The Americans kept on chasing new technologies, primarily emerging from the aerospace field; but restricted themselves only to the development of new generation of battle tanks. For the new family of AVLBs, the Americans were satisfied to integrate the European designs on to their battle tank and wheeled vehicles.

India, by now had established a firm R&D and technology base for military bridging and could produce their own designs for their specific obstacle-crossing equipment, entirely through the indigeneous efforts. T-72-based AVLB could be considered as the world class equipment in its own category. The Table 6.3 gives the typical performance parameters of some of the AVLBs worldwide.

Table 6.3. Typical spans – AVLB

Name of the equipment	Span (m)	Load class
BLT T55	18	MLC 50
MTU 20	20	MLC 60
BLT T72	20	MLC 70
BLT Arjun	26	MLC 70
Leguan - Man	26	MLC 70
CHIEFT AVLB	26	MLC 70
WOLVERINE	26	MLC 70

6.3.1 Armoured Vehicle Launched Bridges – an Introduction

The cold war years kept the two super powers engaged in many developments. Quickly erectable bridges, especially meant for river and obstacle-crossing in the European theater were not an exception to this phenomenon. This gave a new face to the entire military bridging equipment. Assault crossing of any formidable obstacle within a short time frame of a few hours or even minutes became a buzzword. Although the Americans had to join this race, they did not have adequate experience as the other European countries. Thus the UK, France, and Germany remained as the leaders from the NATO side while the Russians ably supported by the Czechs and Poland became the competitors from the Warsaw Pact Nations.

As it would be expected, the cultural differences between these two blocks were evident even in the equipment design and the doctrines – strategies and tactics – differed in many respects. The aim always remained to achieve the element of surprise by negotiating an obstacle-crossing at a time never anticipated. Although crossing of the Suez Canal by the Egyptians in the Yom Kippur war of 1978 stunned the Israelis, India was content with the use of World War II vintage equipment, although the Russian bridging equipment had started arriving just as the war began in December 1971.

6.4 RIVER-CROSSING

The purpose of any river-crossing is to project combat power across a water obstacle to accomplish a mission. A river-crossing is a unique operation. It requires specific procedures for success because the water obstacle prevents normal ground manoeuvre. It also requires detailed planning and control measures and different technical support than other tactical operations require. The nature and size of the obstacle, the enemy situation, and available crossing assets limit the tactical Commander's options. The following are the crossing means that the military use to cross a river:

- Fording vehicles
- Boats
- Bridges
- Amphibious vehicles
- Rafts

Combat vehicles can ford shallow rivers that have a limited current velocity and stable beds. Some vehicles have kits to increase fording depth. Fording is possible for current velocities < 1.5 m/s.

Some combat vehicles can swim. River bank entry and exit points must be clear of obstructions and have slopes consistent with the vehicle's capabilities. The current's velocity sets the limits.

Pneumatic assault boats are the alternate crossing means for dismounted infantry and accompanying elements. For light infantry, assault boats may be the only means required if air support is available.

Heavy rafts are often the initial crossing means for tanks and other fighting vehicles. They are faster to assemble than the bridges and can operate from multiple sites to reduce their vulnerability. Rafts alone cannot handle the total volume of traffic in the required time. Floating bridges are the primary means to cross the force and its supplies rapidly. The same units that provide heavy rafts also provide float bridges. They often assemble bridges from the rafts used earlier.

In Europe, with major rivers flowing across the countries, rafts, and ferrys have been in use for a long time for navigation. This explains the preference for modern ferries over the floating bridges in Europe. The French and German are particularly seen as the world leaders in this field.

Table 6.4. Typical performance parameters

Name of the equipment	Span/set (n)	Performance
PMP	250	MLC 70
PMS	250	MLC 70
Ribbon bridge	250	MLC 80/96 W
Ferry M1	300 (24 bays)	MLC 70/100 W

6.5 IMPROVED FLOAT BRIDGE – RIBBON BRIDGE

Ribbon equipment is designed for use, primarily, during the rafting and bridging phases of the deliberate river-crossing.

6.5.1 Considerations for the Tactical Employment of Ribbon Equipment

Ribbon bridges and rafts are significantly faster to construct with fewer personnel than other floating bridges, so, these are heavily relied upon in this capacity. Site considerations are of primary importance when ribbon equipment is to be used for rafting or bridging operations. Both the launch sites and actual bridge or raft sites should be considered.

6.5.2 Site Selection

Site selection depends upon several factors. Generally, ribbon equipment is launched downstream from bridge or rafting sites to allow for ease of construction and to prevent runaway bridge bays from damaging other equipment or injuring personnel. Other selection criteria include the height of the banks, the bank slopes, and the depth of the water at the site. There are four methods of launching ribbon equipment (Fig. 6.3):

(a) Free launch

(b) Controlled launch

(c) High bank launch, and

(d) Helicopter delivery

6.5.3 Raft and Bridge Sites

The tactical plan plays a major role in the selection process. Some factors which apply to ribbon equipment are described in succeeding paragraphs.

6.5.4 Water Depth (draft) Restrictions

Water depth restrictions are given below. The ribbon bridge system consists of three major components: bridge transporters, interior bays, and ramp bays. Although bridge erection boats are not a component of the ribbon bridge system, boats are required for the propulsion of ribbon rafts as well as for the assembly and anchorage of ribbon rafts and bridges.

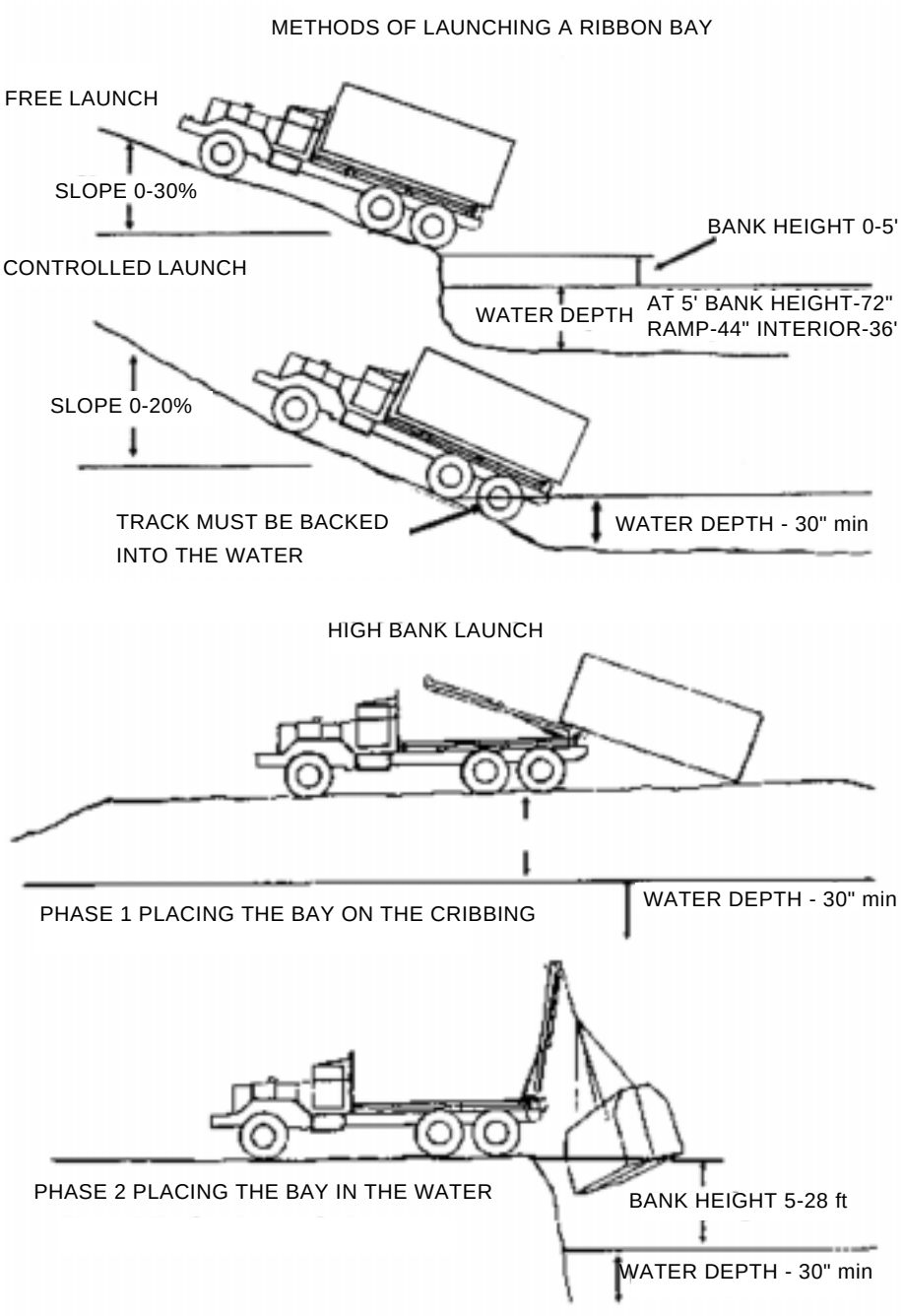


Figure 6.3. Methods of launching ribbon equipments.

6.5.5 Bank Restrictions

The ribbon ramp bay can articulate a maximum of 20 ° from its horizontal position. This means that the maximum allowable bank height for loading or unloading of ribbon rafts/bridges is about 107 cm. The shore leading to the raft or bridge ramp should be gently sloping (no more than 20 per cent slope), generally free of rocks or other debris, and firm. Other dimensions for ramp bay are given in the Fig. 6.4.

DIMENSIONS	
LENGTH	19 ft 7in
LENGTH (APPROACH RAMP EXTENDED)	25 ft 4in
WIDTH (FOLDED)	10 ft 6in
WIDTH (UNFOLDED)	26 ft 8in
HEIGHT (FOLDED)	7 ft 10.1 in
HEIGHT (UNFOLDED)	3 ft 7in
WEIGHT	11,700 lb

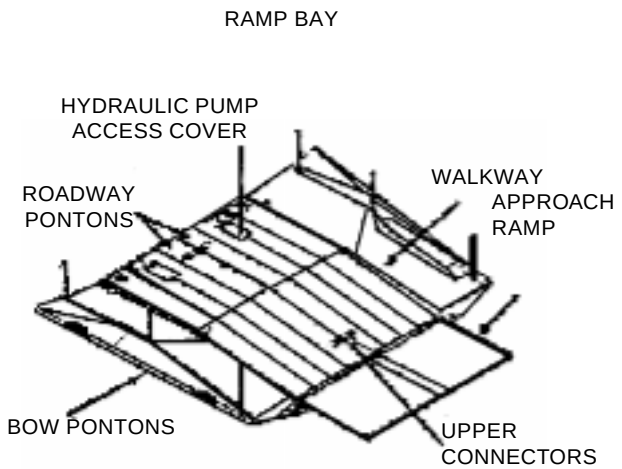


Figure 6.4. Important dimensions for ramp bay.

6.5.6 Current Velocity

The river velocity can impact significantly all float bridging operations. Ribbon equipment can be used in water currents of 0–10 FPS. Rafting and bridging operations can become quite difficult in water currents >5 FPS unless the boat operators and bridge crewmen have experience working in swift currents. For raft sites on rivers with current >5 FPS, the unloading site on the far-shore should be located downstream of the loading site on the near-shore to allow for downstream drift.

6.5.7 Launch on High Banks

The high bank launch must be used when the bank height at the launch site is between 152 cm and 4267 cm. This method is normally used only when a more desirable site is unavailable (Fig. 6.3). This process has two distinct phases:

(a) Off-loading of the bay onto the ground. The transporter is manoeuvered parallel to the bank and the bay is lowered onto the ground. Cribbing is used to prevent damage to the bay.

(b) The transporter to be backed perpendicular to the bay. Chains are attached to the four lift points on the bay and the transporter cable is run through the snatch block and attached to the truck's boom. The boom can then be used to lift the bay off the ground and place the bay in the water. If the bank is not completely level, some means of restraining the front-end of the truck should be used to prevent the truck from overturning. Water depth of approximately 80 cm is desired for the high bank launch although the launch can be carefully conducted in 43.18 cm of water. A bridge erection boat (BEB) is required to secure the bay once it is in the water. The boat operator allows the bay to unfold by opening the downstream travel latch.

6.6 INTERIOR BAY

The interior bay is the primary load carrying component of a ribbon bridge or raft. Each interior bridge bay is a four-ponton, folding module consisting of two roadway pontons and two bow pontons. The interior roadway pontons are joined to each other and to the adjacent bow pontons by hinges and pins along their adjacent edges. The roadway is welded to the roadway pontons, thus eliminating the need for separate intermediate pneumatic supports. One interior bay provides a roadway that is approximately 411.48 cm wide (13 ft 5 inches). The two bow pontons aid in flotation and provide walkways for personnel on both sides of the roadway.

6.7 RAMP BAY

The ramp bay is similar in construction to the interior bay, except that the bay's shore-end is tapered. Ramps are always attached to both ends of a ribbon raft or bridge. A hydraulic system located within the ramp bay permits the ramp to be raised to accommodate bank heights of up to 106.68 cm. Two extensions of 214 cm each serve as approach ramps, are hinged to the roadway ponton on the shore side of the ramp to allow for ease of loading and unloading vehicles from bridges or rafts.

6.8 BRIDGES AND OTHER EXPEDIENTS

Other expedients such as combat engineer tractors, trackways, fording mats, mine laying and clearing equipments, and boats are already covered in Chapter 3.

In the mountain warfare, the foot soldier has to cross canals, rivers, and other obstacles by swimming, by using inflatable boats or by ferrying. This has to be followed with continuous reinforcements which include supplies, arms, and ammunitions. Apart from foot soldiers, the RCL guns, and jeeps have also to be taken across.

The glacier warfare has its own special requirements, which are more demanding for performance owing to the high altitudes, low temperatures, and enemy fire.

6.9 BRIDGES OF WORLD WAR II

Military truss bridges (e.g., Bailey bridges) were pioneered in World War II by the highly successful British invented Bailey bridge which played an important role in the allied campaign in Italy in the final stages. In December 1940, EBE received approval to construct a pilot model of a bridge using a new basis for design. Its manufacture involved the welding of high-tensile steel, a novel process in 1940. Donald Bailey had proposed the idea of a bridge made of flat panels before the war but the proposal had been shelved for economic reasons. Design began in December 1940, the pilot model was ready for test in 1941 and the first production bridges were in-service in December 1941 just before the arrival of the Churchill tank. Over 600 firms worked in the production of the bridge.

During the last three years of the war some 5 lakh tonne of bridge equipment were manufactured, representing over 200 mile of Bailey bridges. Bailey bridging made an immense contribution towards the final victory in World War II. It could never have been possible to maintain the speed and tempo of forward movement without large supplies of Bailey bridges (Fig. 6.5–6.6).

Also during World War II, the scissors assault bridge was introduced; a folding bridge, hinged at their juncture, was carried to

Figure 6.5. The pontoon-supported bridge concept was first introduced in the Bailey, which was followed by other countries like Germany.

Figure 6.6. The rubberised pontoon-supported bridge concept was adopted by the Germans for their Krupp Maan floating bridge which was later imported by India to replace the Bailey pontoon bridge.

Figure 6.7. Conceptual design of a scissor bridge having pipe crossing capability.

Figure 6.8. The Indian scissors launched bridge - *Kartik*.

the river bank on a covenanter tank; opening out in an inverted V and spanning just 9.14 cm as shown in Fig. 6.7. Indian scissors bridge *Kartik* is shown in Fig. 6.8. A similar system is followed for the Churchill tank. Also, heavy pontoon bridges became common along with Bailey and provided acceptable solutions of river crossings in many theaters.

6.9.1 Manually Launched Bridges

The medium girder bridges (MGB), UK or its Indian counterpart manually launched assault bridges (MLAB) is a hand-erectable, heavy-duty, prefabricated deck bridge consisting of high-strength aluminium alloy components, which can be assembled into different configurations. The MLAB and the Bailey are considered complementary systems, each satisfying different operational requirements. The primary role of the MLAB is for tactical bridging in the brigade area, while the Bailey bridge is used primarily as a line-of-communication bridge. As the tactical situation permits, MGB would be removed and replaced by Bailey, timber, or steel bridges (Fig. 6.9–6.10). However, in the years to come, the MLAB may well serve as the line-of-communication bridge and other modular bridges with mechanical aids may serve as assault bridges.

The key advantages of the MLAB over the Bailey are speed and ease of erection as also the modularity. MLAB in different combinations can cover gaps from 9.8 m to 50 m. The manpower, construction party and timings are greatly dependent on the selected configuration, which varies from single storey to double storey with reinforcement kit (Fig. 6.11–6.12).

Although, manually launched bridges cover a wide spectrum of load-carrying capabilities, infantry needs manually constructed bridges for light loads and very small teams. Infantry bridges may carry jeeps, guns or only men. In the Indian context, for glacier region, crevasse crossing equipment is needed (Fig 6.13). Even infantry bridges may need floating variants or helicopter emplacement capability.

One of the important concepts for the manually launched bridges is that of palletisation which expedites the speedy construction at site. This is shown in Figures 6.14 (a) and (b). Figure 6.15 shows seven major components of MGB/MLAB.

Figure 6.9. Adding a bay of the manually launched MGB is a skilled operation.

Figure 6.10. MGB being used as a pontoon-supported bridge for crossing a river.

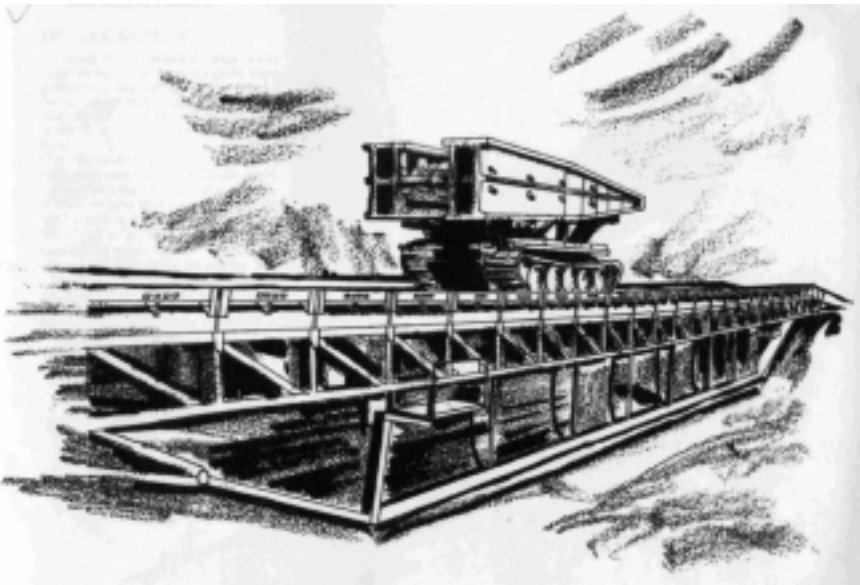


Figure 6.11. MLAB – the Indian version of the MGB demonstrates increased span capabilities with a reinforcement kit.

Figure 6.12. The single storey version of the MLAB can span up to 9.8 m for MLC 70 loads.

Figure 6.13. An aluminium or FRP bridge is ideally suited for high altitude crevasse crossing.

Figure 6.14 (a). MGB/MLAB pallet being mechanically off-loaded.

Figure 6.14 (b). Manual off-loading of the same pallet.

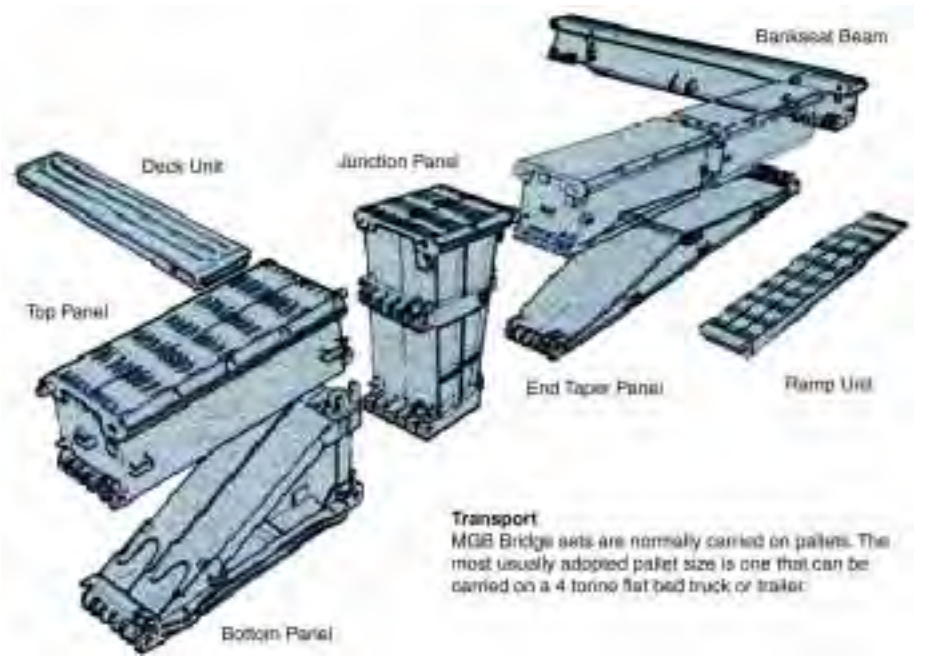


Figure 6.15. Seven major components of MGB/MLAB.

6.9.2 Details of Armoured Vehicle Launched Bridges

The Armoured Vehicle Launched Bridges (AVLB) allows the manoeuvre force to conduct a hasty short gap crossing without requiring bridging assets from the corps. The AVLB allows vehicles up to 70 tonne to cross over varying gaps (26 m maximum).

During the launch, the AVLB presents a high profile that reveals the bridging location. To overcome this drawback, sliding bridges have been used, especially by the Germans and the Americans. The bridge can be launched on the near-shore and then recovered on the far-shore and used again.

Many countries have their own versions of AVLBs. The first version of an AVLB which came towards the later part of the World War II did not prove very effective. Figure 6.16 shows the Soviet MTU-20 AVLB. In India, it is 20 m span T-72 based bridge layer tank (BLT) (Fig. 6.17), while Chieftain AVLB (UK), Leopard-based Leguan (Germany) (Fig. 6.18), Abrahams-based Wolverine (USA) (Fig. 6.19 a & b), and some East European versions based on T-55 and T-72 tanks are some of the prominent AVLBs in the world. The trend in the future, however is towards modularity, span variations, and NBC

Figure 6.16. Soviet version of AVLB - Soviet MTU-20 AVLB.

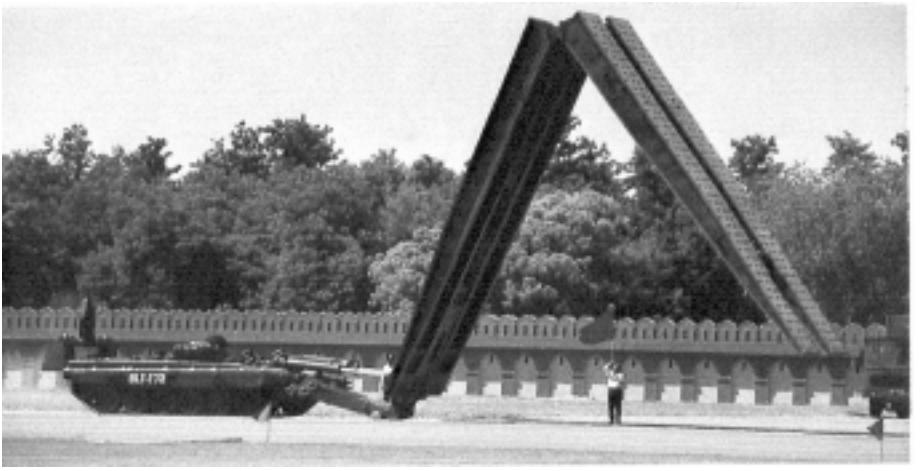


Figure 6.17. The Indian bridge layer tank (20 m) on a T-72 tank chassis.

protection. The wheeled vehicles are ideally suited for incorporating modularity in spans, load classes, and width of the bridge. The combination with trestle legs can provide very long span crossing capabilities, from 75 m to 100 m.

6.9.3 Wheeled Vehicle-mounted Bridges

The present worldwide trend is towards the development of rapid deployment forces. The engineer support to such forces is of utmost importance to ensure adequate strategic mobility as well as tactical mobility over land spanning several hundred kilometers. In this respect, only wheeled vehicles provide a satisfactory solution over the tracked vehicles. The automotive technology is now well developed that wheeled vehicles can match the cross-country performance of the tracked vehicles. When considered with the progress on the bridge designs, the modularity that can be accommodated on wheeled vehicles, far exceeds the tracked vehicles capabilities. In addition, the wheeled vehicles allow the bridge designer more freedom to translate his ideas in to more efiicient designs.

East European countries in the 1950s were leaders in the field of wheeled vehicle-mounted bridges. The basic concepts developed by

Figure 6.18. The German bridging system Leguan mounted on wheeled vehicles.

Figure 6.19(a). **The sliding concept preferred by the Germans and the Americans is demonstrated on Wolverine of the US Army.**

Figure 6.19(b). The sliding launch of Wolverine in progress.

Figure 6.20. The latest Russian system – KMT-6 – with increased span capabilities.

the Russians have been adapted by others to bring into market a new generation of wheeled bridges. Prominent amongst the bridges are *Sarvatra* by India, Leguan by Germany, Bridges of 1990s by the UK, REBS by the USA, and KMT-6 by Russia (Fig. 6.20).The trestle-cum-span concept of the Soviet origin is a very innovative concept, adopted and improved in performance by the Indians for their popular bridging system *Sarvatra* (Fig. 6.21 a & b). The TMM-3 bridge of the Soviet origin was the pioneer in the trestle-cum-span bridges (Fig. 6.22).

6.9.4 Floating Bridges

River crossings are technically difficult feats of amazing technology and skill. To get vast amounts of heavy equipment across a major river, the engineers have to worry about water currents, muddy banks, steepness of the banks, depth of the water, and accurate data on the exact span. These parameters can be controlled by the enemy as the

Figure 6.21(a). Indian bridge - *Sarvatra*.

Figure 6.21(b). ***Sarvatra*'s multi-span capability is fully exploited here on Ganga canal where it spans 75 m and the pier legs are supported on poor soil.**

Figure 6.22. TMM-3 bridge of Soviet era.

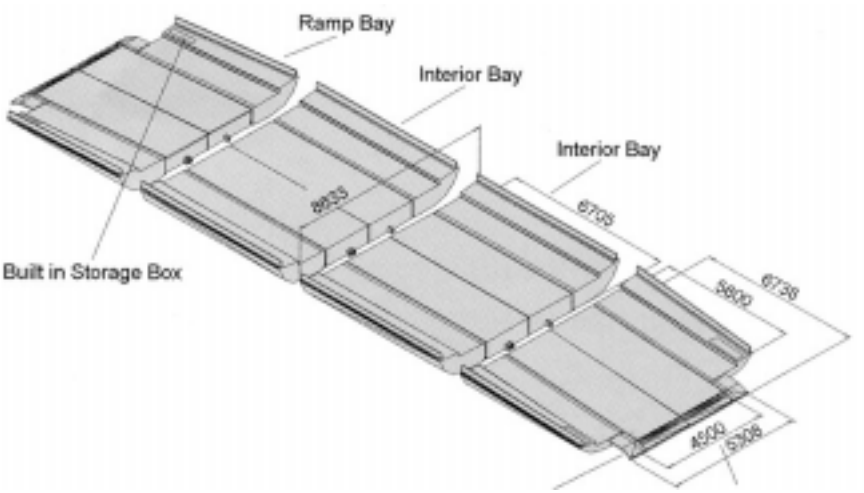


Figure 6.23. The typical section of a floating bridge showing a very wide roadway and the modules such as interior and end bay.

Figure 6.24. The bays are joined when they are floating freely in water.

operation starts, making the success of the operation extremely unpredictable. Figures 6.23-6.24 can help understand the basic concepts of a floating bridge pioneered by the Soviets.

The Soviets had designed and deployed a large number of innovative folding bridges that could be transported on trucks and unfolded automatically as they fall into water. The Egyptians used one such equipment PMP bridge during the Yom Kippur war with total success for crossing the Suez canal. The concept was so good that after the war, when Israelis could capture one of the bridges, many European countries and the USA copied the concept with their own variations. The PMP/PMS Pontoon bridge is made up of several sections (Fig. 6.25). Some of the sections have ramps and supports to secure the structure against steep river banks; others are designed to attach to the end sections and float on pontoons in the middle of a river. At the touch of a series of controls, the bridge sections slide off the back of the truck and unfold as they hit the water. When these are deployed, tugs push the sections together. Soldiers then secure them to each other. The overall span is no problem. Typically, a set, however would comprise 250 m length of the bridge. An Israeli concept of a floating bridge launched using a pontoon support is shown in Fig. 6.26. Figure 6.27 shows how a fully constructed floating bridge provides a highway on the battlefield.

6.10 MILITARY BRIDGES FOR CIVIL APPLICATIONS

The civil bridges are permanent structures; while military bridges are essentially temporary structures. Military bridges are countermeasures to man-made disasters. In warlike situations, the obstacles are to be cleared in the shortest possible timeframe and under adverse conditions. Apart from specific designs worked out to achieve these goals, elaborate planning is a key factor.

In natural disasters like floods, earthquakes, and cyclones, similar requirement exists; but one hardly finds any advance planning for this problem. Military help is invariably sought for providing solutions; but the military itself is not equipped for planned disaster mitigation programmes. Railways have a system in place– relieving girders. However, the existing system is outdated and does not meet

Figure 6.25. The PMP/PMS Pontoon bridge takes full advantage of the buoyancy principle to unfold the boat and make the complete roadway.

Figure 6.26. An Israeli concept of a floating bridge launched using a pontoon support.

Figure 6.27. A fully constructed floating bridge provides a highway on the battlefield.

Figure 6.28. The military bridge concepts have been used for emergency operations and establishment of rapid communications in parallel with conventional bridging construction.

Figure 6.29. The Indian GRSE bridge.

Figure 6.30. The Mabey bridge, UK is based on the Bailey concept; but is primarily meant for civil applications.
Source: Taken from Mabey Bridges, UK

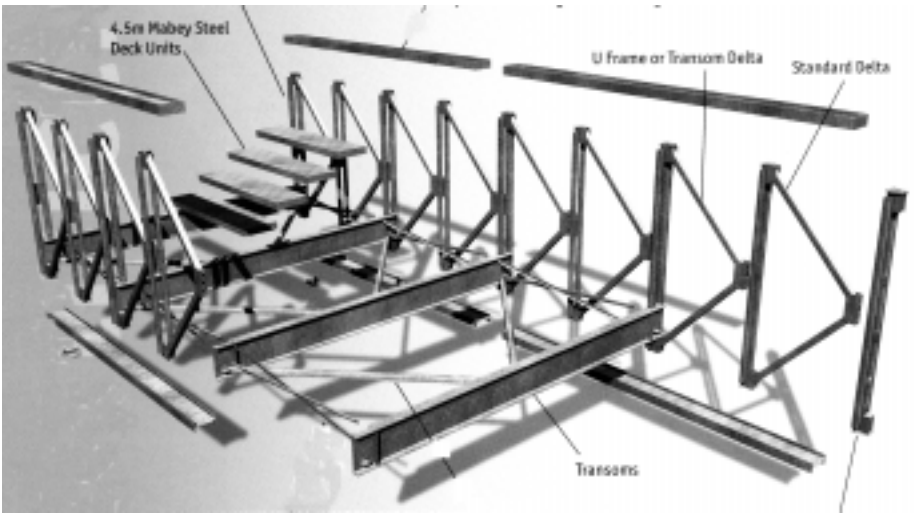


Figure 6.31. The basic elements of a Mabey bridge.

the modern requirement of speedy restoration of the communication system.

The Bailey bridge developed and extensively used during the World War II, is an excellent example of conversion to the civilian application. In India, the entire border road network was created using the Bailey as the primary bridging system. As the technology for new materials advanced, Bailey's variants were developed by quite a few companies to provide solutions for bridging in the construction industry. The Indian GRSE bridge is a kind of improvement over the Bailey where high-strength steel is used (Fig. 6.29).

With the advances in materials, many high-strength steels are now available. Adding latest surface-finishing techniques ensured the corrosion resistance. Availability of material-handling systems ensured that the earlier limitations on the individual component of the bridge were no more valid. M/s Mabey, UK is the leader to develop many Mabey bridges for applications by the civilian construction industry (Fig. 6.30-6.31). M/s Garden Reach Shipbuilders, Kolkata also took out their version of the bridge for civilian applications.

CHAPTER 7

RELEVANT TECHNOLOGIES

7.1 BACKGROUND

The history shows that man has been fighting with his own race ever since the time immemorial. As he started inventing weapons, different methods of attack and defence came to his mind. One can spot a number of examples of the use of contemporary materials to develop new weapons and protections, which were continuously improving performance since the rule was survival of the fittest. Military bridges, although not considered as weapons, were no exception to this. Examples are plenty; such as the *setu* built to Lanka from Rameshwaram and a number of stone arch bridges that were constructed by the Greeks and Romans more than a millennium ago. During the fifteenth century, Leonardo da Vinci had sketched quite a few innovative concepts for military bridges like a draw bridge, pontoon bridge, and a trestle-cum-span bridge. The coming of the steel age, the automobiles and tanks saw a sudden impetus to a new class of military bridges such as Hamilton bridge during the World War I. The World War II saw a spectacular proliferation of battle tanks in the European theater. The development of steels of different grades, alloy compositions, and manufacturing techniques, saw a sudden spurt in the development of high performance bridging equipment like Bailey bridging equipment. The Bailey bridge made historic contributions to the allied military effort. Though Bailey bridging equipment was considered as close support or assault equipment, the AVLBs were yet to follow. Since, the MBT was also becoming heavier and heavier, there were demands on the materials and design of the AVLBs to perform better. In the rapid developments that followed during the war, the technology for steel compositions and welding was pushed to

new heights. This made it possible to achieve spans of 18 m from the initial limitation of about 10 m. In the process, maraging steels and their welding techniques were also developed. Though considerable work had been carried out on development of new aluminium alloys like Duralumin for the aircraft industry, the progress on structural applications was rather tardy. It was only after the end of the World War II that considerable work was carried out on a new family of weldable aluminium alloys.

7.2 PERFORMANCE IMPROVEMENT FACTORS

The performance of military bridges is dependent on the progress made generally in the field of design of structures, which in turn depends upon the following:

(a) Development of new materials
(b) Improved efficiency of the designs
(c) Mechanisation and automation
(d) Innovative ideas in anatomy and stowage of the components.

7.3 ANATOMY AND STOWAGE

Let us consider these four factors in a reverse order. If we take the anatomy and stowage, one can see clearly two separate schools of thought, one propagated by the British, viz., the scissoring launch. Almost for the last half a century, the British have favoured this method of launch due to its ruggedness and simplicity. A spade or a bearing pad acts as a fulcrum during launch. The effort required for the launch is more, but the demand on the counterweight is somewhat less. Also, the scissor method is simpler for design and operation and has less number of steps to go through during launch. This results in improved reliability, especially in the field.

The Soviet countries always preferred scissor launch probably for the reasons of simplicity and robustness. They not only put the scissor launched bridges on the battle tanks; but also put such bridges on their high mobility wheeled vehicles, the designs of which were also unique. Typically, Tatra 8×8 vehicle had a high payload capacity of about 10 tonne and its central tube design gave it some unique

Figure 7.1. A scissor-type bridge launched from tatra chassis.

advantages. Moreover, they could take advantage of the triangular portion at the end of the bridge to provide space for mounting pier legs, which gave these bridges multi-span capabilities. Figure 7.1 shows the view of a scissor launch bridge and the tatra chassis.

The sliding launch on the other hand needs somewhat less effort to launch. The requirement of the counterweight is much higher and therefore the cantilever structure should necessarily be a minimum weight design to make longer spans possible. The number of operations during the launch are somewhat more. That makes the design more complex and the equipment less robust. Since the entire forward movement of the bridge depends upon minimum friction, there has to be a precision manufacture of the launching mechanism. The moving parts should also be protected from the sand, dust, and temperature/humidity effects. Figure 7.2 shows a schematic view of a typical sliding launch, which is always preferred by the Germans.

7.4 MECHANISATION AND AUTOMATION

Most of the bridging equipments developed and deployed during the World War II were meant for manual construction. Typically those equipment required several trucks, drivers, and

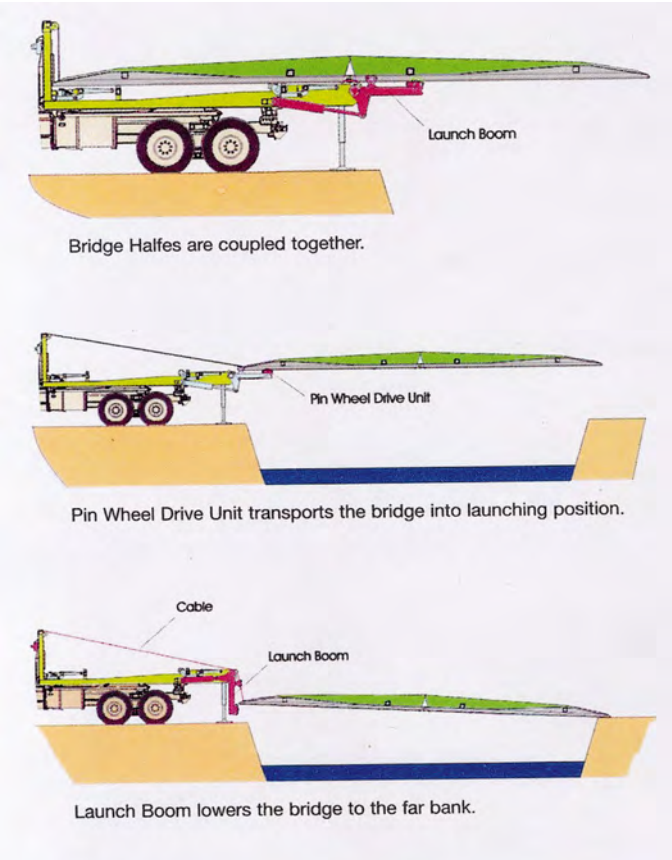


Figure 7.2. The sliding launch concept.

construction crew. In the modern warfare, such a resource cannot be spared. The AVLBs that came on the horizon towards the later part of the war provided excellent solution to these problems. Thus, an 18 m bridge could be mechanically launched from the vehicle by a crew of only two or three. This was possible using mechanical aids. The basic principle was the same as used in the material handling and earth-moving equipment that was in vogue for a variety of industrial applications. Also, the power available from the prime mover of the vehicle could be readily used to aid folding, unfolding, and launching of the bridge.

The most common form of mechanical application was the use of the fluid power or hydraulics. A power take off (PTO) unit was the

natural choice for the power source. To make the system very compact, high pressure hydraulics was used extensively. By high pressure what is meant is the pressure of 300 bars (kg/cm^2). This was a deviation from other industrial applications that depended upon maximum pressures of 200 bars (kg/cm^2). This difference in approach was justified by the fact that the industrial applications had to be more frequently used for prolonged durations. Use of high pressure for military applications made the systems more compact and light weight. Also the modular approach, that was preferred for military applications, made the systems more dependable. Basically, the components of any hydraulic system would comprise cylinders, valves, motors, winches, and accumulators.

With the advent of electronics and programmable logic controllers during the 1980s, the mechanical systems used for launching operations got a tremendous boost for improved performance. It was now possible to program the launching sequence as per the predetermined drill and to carry out various checks on the system's behaviour as the launch progressed. This was also a natural extension of industrial application, especially in the machine tool and automobile industry. This new branch of engineering, known as Mechatronics, provided excellent solution especially for NBC environment. Not only it was possible now to launch the bridge without coming out of the tank, but it was possible to achieve an improvement in reliability factor. Also, such systems could be easily simulated, and therefore, it was possible to train the crew without excessive use of the equipment, thereby battlefield readiness could be improved substantially.

7.5 EFFICIENCY OF THE DESIGN

There has always been a craving for achieving minimum weights for the designs so that the mobility of the carrying vehicle is not affected and it can closely follow the MBT in any operation. Alternatively, for the same gross weight of the vehicle, the bridge could be designed to span longer gaps. For the aircraft industry, optimised solutions are so important that the design philosophy is carried to very high levels of

sophistication and expense. Obviously, more robust army equipment cannot follow this example in true sense. Yet, some basic principles of design are common and can be effectively used to reduce the weight. For example, the use of advanced computer methods of structural analysis can provide valuable information on the stress distribution, fracture mechanics, and failure modes. The finite element analysis (FEA) methods can be used by trained engineers with advantage. These methods can also indicate points where stress concentration could pose some problems, especially for the fatigue behaviour. These techniques can also be used effectively for working out fail-safe designs, which can avoid catastrophic failures.

The aircraft industry depends heavily on sophistication amounting to evolving more and more complex designs. Even if the examples of the aircraft industry in this respect are followed, the fact remains that more complex designs produce diminishing returns in weight saving. This is illustrated by considering a simple framed structure to carry a given load over a given span. Starting from the basic geometry of a framework consisting of seven members, and then achieving weight reduction using more lighter members, until in the limit the framework consists of an infinite number of members, each of zero weight, leads to the conclusion that however complex the framework is made, the maximum weight reduction is 20 per cent. This is why newer materials assume more importance than the expensive structural techniques of the aircraft industry.

7.6 SELECTING NEW MATERIALS

The twentieth century saw phenomenal progress in the development and use of a large variety of new materials. During the World War II, the demand for new materials was so great that no adequate alloy designating methodology was available. Therefore, an emergency numbering system was evolved, which became permanent even after the end of the war. Thus, came the emergency numbers for steels known as EN series steels. The end of the war did not end this race for new materials, the pressure coming from the aerospace industry. Development of high-strength steels including maraging steels prompted

the engineers at Christchurch to design a new military bridge Chieftain AVLB in maraging steel. The real breakthrough, however, was achieved in the 1960's when a new weldable and self-ageing alloy was developed in the UK, followed by Germany.

Somehow, the erstwhile Soviet countries have depended only on medium/high-strength steels for military bridges, whereas the UK, Germany, and India have preferred special aluminium alloys for their bridges. The physical properties that affect the designer's choice and their implications to aluminium alloys are enumerated below:

(a) **Strength to weight ratio**: When compared to mild steel, aluminium alloys have a better strength to weight ratio advantage ranging from 2 to 3. There will be a corresponding cost disadvantage, approx. of the same magnitude.
(b) **Modulus**: Low modulus of aluminium or its alloys make their use in columnar structures (which are designed primarily against buckling) unattractive. However, when bending stiffness of plate is considered, weight-to-weight, aluminium plate can offer higher-stiffness than the corresponding steel plate.
(c) **Toughness**: While more ductile material is preferred from fracture mechanics angle to provide adequate warning before failure, poor ductility of aluminium alloys could be improved by controlling trace elements such as iron and silicon. It is possible to avoid catastrophic failures by meticulous planning. There are many aluminium alloys in the 7000 series, such as 7050 and 7045, which have been specifically developed for their high-toughness.
(d) **Stress corrosion**: Medium-or-high strength aluminium alloys invariably suffer from stress-corrosion problems. Stress-corrosion effects could become visible during early service life even in storage and could make the bridge unserviceable prematurely. This is a serious defect and can be more pronounced in tropical and corrosive environment. Indeed during 1970s, one of the floating bridging equipment imported by India from Germany suffered from stress-corrosion cracking. The production agencies could find a satisfactory solution only after considerable experimental work. The normal tendency of the manufacturer is to get liberal tolerances

in chemical composition with no specific constraints on microstructure so that rejections at the production stage are minimum. If adequate care is not taken in selecting the material and the process, stress-corrosion problems could surface later. Thus, proper understanding and education on the part of the designer and the producer helps a great deal to obviate major problems later.

At this stage, it may be worthwhile to have a look at the alloy designation system, which is universally followed. Since most of the aluminium alloy products for bridging equipment are in the wrought form, the designation system and tempers relevant to this form only are considered here. The main features of designation and typical applications are as under:

First digit – Principal alloying constituent(s)

Second digit – Variations of initial alloy

Third and fourth digits –

- 1xxx – Pure *Al* (99.00 per cent or greater)
- 2xxx – *Al-Cu* alloys
- 3xxx – *Al-Mn* alloys
- 4xxx – *Al-Si* alloys
- 5xxx – *Al-Mg* alloys
- 6xxx – *Al-Mg-Si* alloys
- 7xxx – *Al-Zn* alloys
- 8xxx – *Al*+ other elements
- 9xxx – Unused series

Tempers

- *F* – As fabricated
- *O* – Annealed
- *H* – Strain hardened (wrought products only)
- *W* – Solution heat treated
- *T* – Thermally treated to produce tempers other than *F*, *O*, *H* (usually solution heat treated, quenched, and precipitation hardened)
- Numeric additions indicate specific variations
  e.g., *T*6 = Solution heat treated and artificially aged

The principal characteristics and applications of the above alloys are-

- 1xxx – Pure *Al*
  1100, 1350
  Strain hardenable
  Corrosion resistance/ductility/weldable
  Electrical/chemical applications
- 2xxx – *Al-Cu* alloys
  2014, 2024, 2219
  Heat treatable
  High-strength/toughness
  Aircraft/automotive/truck/fastener applications
  Weldable by special techniques; 2219 readily weldable
- 3xxx – *Al-Mn* alloys
  3003, 3004
  Strain hardenable
  Corrosion resistance/weldable
  Heat transfer/packaging/roofing-siding applications
  3004 is major can body alloy
- 4xxx – *Al-Si* Alloys
  4032
  Heat treatable
  Good flow characteristics
  Pistons/complex shaped forgings
  4043 is widely used filler alloy for welding
- 5xxx – *Al-Mg* alloys
  5052, 5083, 5086, 5182, 5754
  Strain hardenable
  Medium-strength/exceptional toughness/corrosion resistance
  Exceptional cryogenic properties; proven tough to near absolute zero (-270°C)
  Building&construction/automotive/marine/cryogenic applications
- 6xxx – *Al-Mg-Si* Alloys
  6061, 6063, 6111
  Heat treatable
  Corrosion resistance/strength/extrudability
  Building & construction/automotive

- 7xxx –s *Al-Zn* alloys
  7005, 7050, 7075, 7475
  Heat treatable
  High-strength
  Special high toughness alloys (7050, 7150, 7475)
- Caution must be exercised on susceptibility to stress corrosion cracking; use special corrosion resistance tempers (e.g., *T* 73)
- Aircraft/aerospace applications, military bridges and other structures requiring good weldability.

Welding is a powerful tool for fabricating aluminium structures. In many cases, welding is both the most cost effective and structurally sound joining technique available. To effectively use welding, designers must become familiar with the characteristics of aluminium and aluminium weldments. Joint design is a parallel development of the joining process, material specification, and part design. The joint often determines the structural performance of the part, so attention must be given to joint design wrt performance, quality, and manufacturing.

To specify any fabrication technique, determine the critical performance issues that the joining method must address. The most common structural requirements of a joint are strength, ductility, toughness, and fatigue strength. However, other requirements may include aesthetics, corrosion resistance, or electrical conductivity. Often, joints are required to simultaneously address many of these issues.

To effectively design welded aluminium joints, one must understand the material. Aluminum is not one material, but many different alloys. These alloys vary significantly in their weldability and in their weld performance. The specific welding process also substantially interacts with the material to affect weldability. A designer must select materials that are suitable for the welding/joining process to be used (or vice versa). A common misconception that aluminium is not readily welded comes from the fact that airplanes are most frequently riveted or bonded in assembly. However, this is largely because aircraft designers specify aluminium alloys that are not readily welded. Moreover, the use in aircraft industry is primarily in

thin-sheet form, which is not easily welded. In some cases, welded joints in common alloys can outperform riveted joints in high-strength aerospace alloys.

There are several standards and data books that give weldability ratings for many common welding processes and alloys. These tables should be consulted before specifying an alloy or welding process. For high-volume production or general fabrication, *A* weldability ratings are recommended.

Over the past three or four decades, 7000–series aluminium alloys have become the natural choice for a military bridge designer. The following tables give comparison of some prominent aluminium alloys used the world over for military bridges.

Alloy designation	**Zinc**	**Magnesium**	**Manganese**	**Zirconium**	**Ultimate tensile strength (Mpa)**	**0.2 proof stress (Mpa)**	**Per cent elongation**
DGFVE -232	3.8-4.2	1.8-2.2	0.25-0.45	0.1-0.25	400	344	10
Konstruktal /*Al-Zn-Mg*1	4.5	1.4	-	0.1-0.5	360	281	10
RDE 32	4.3-4.7	1.1-1.4	0.2-0.45	0.1-0.25	315	268	10
RDE 40	3.8-4.2	1.8-2.2	0.25-0.45	0.1-0.25	400	344	8 50 mm Gauge length

Alloy designation	**DGFVE-232**	**Konstruktal**	**RDE-32**	**RDE-40**
Country	UK	Germany	India	India
International designation	7020	7020	7020	7004
Used in	MGB BR 90	KruppMAN Leguan Wolverine	Fixed bridge Class 3	MLAB *Sarvatra*

Specifications, standards and design codes for aluminium alloys evolved slowly after their introduction. Thus, this activity was always behind of other materials of construction, most notably concrete and

steel. In the USA, UK, and Germany, different standards and design codes were brought out with the main objective of making this new material more competitive with the other conventional materials. For example, in 1994, the Aluminum Association, USA, released a substantially revised edition of the specifications as part of a new publication, the Aluminum Design Manual. Additionally, the Association published the first load and resistance factor design (LRFD) version of the specifications, consistent with the new approaches to reliability used for concrete and steel. The revised specifications contain methods needed by engineers to exploit aluminum's structural uses in new ways and to win competitions with other materials.

7.7 MEMBERS IN COMPRESSION

Regardless of the philosophy used to determine the margin of safety, all design specifications must first establish the strength of structural components made of a given material. But how is strength defined? Some members composed of thin elements may show visible buckles when loaded, but still be capable of resisting additional load before collapse. Such behavior is called post-buckling strength. An example is an extruded I section column with thin flanges. When the column is compressed, waviness may be observed in the flanges, but the column does not collapse, and when the load is removed, the waviness disappears. The latest aluminium specifications contain provisions that enable engineers to take advantage of the postbuckling strength of such members for the first time.

One of the aluminium industry's most potent weapons in competing with other materials is the variety of shapes that can be produced readily by extruding. Designers of extrusions have long been familiar with the strengthening effect of a stiffener located along the edge of a flange or of a rib running along a wall of an extrusion. The new specifications contain provisions for quantifying the beneficial effects of both ribs and relatively small-edge stiffeners in compression zones in columns and beams. Columns with unsymmetric cross-sections and certain cruciform sections (both readily extruded) may

buckle in a combined lateral bowing and twisting manner. The new specifications give equations to quantify this behaviour, referred to as torsional-flexural buckling. The new specifications contain precise expressions for predicting the lateral torsional buckling strength of beams as well.

7.8 MEMBERS SUBJECTED TO REPEATED LOADINGS

Certain members, such as bridge girders and aircraft frames, are subjected to many repetitions of load. It has long been known that a load not big enough to cause fracture upon one application, can cause failure if it is repeatedly applied. This behaviour is called fatigue by structural engineers. Although fatigue is not a new issue, it was not until 1986 that design provisions for determining aluminium fatigue strengths were included in the aluminium specifications. Even then, only fatigue loads of constant amplitude (exactly the same load applied each time) were addressed. In the real world, members are typically subjected to loads of different magnitudes at different times (such as bridge traffic including trucks of varying weights), called variable amplitude loading. The new specifications include updated fatigue strengths and, provide design rules for variable amplitude loads.

7.9 LOAD AND RESISTANCE FACTOR DESIGN

Until around 1960, all structural standards used allowable stress design (ASD) to ensure a margin of safety against failure. Stresses produced by loads (such as wind blowing on a highway sign) were calculated and compared to stresses at failure divided by a factor of safety (called allowable stresses). Accepted factors of safety evolved over time as experience with acceptable and unacceptable service histories accumulated. Factors of safety were also adjusted for different end uses, types of stress, and material. For example, aluminium bridge members were designed with a safety factor of 2.2 against fracture, while for the same member in a building a lower factor 1.95 was used. Engineers devised a design philosophy called load and resistance factor design (LRFD). This approach uses probability and statistics to determine two sets of factors. Resistance factors are used to factor down the nominal strength, or resistance, of a structural member to

account for uncertainties introduced by variations in material, fabrication, and design. Load factors are applied to nominal loads to account for imperfect prediction of their magnitude and the probability of their acting in combination with other loads. Resistance factors are a function of the material, while load factors can be the same whether the structure being designed is a wooden temple or an aluminium space frame. Concrete was the first material for which LRFD specifications were written, followed by steel in 1986 and aluminium in 1994. By now, it can be concluded that aluminium has reached a stage of a mature structural material for which all the unknowns are now known. This can push aluminium in new application areas apart from defence and aerospace, in which sectors it has become the mainstay of the designer.

7.10 COMPOSITES – A MATERIAL OF THE FUTURE

While many new materials had appeared on the horizon by the time the World War II had come to an end, newer developments had started to find their roots, thanks to the automobile and aerospace industries which had started experiencing a tremendous growth. Just like the nations, the materials were competing. In this list was an altogether newcomer, composites or reinforced plastics, which had a modest start in the ship building industry in the early 1940's. This material later became a major threat to aluminium. Thanks to a number of advantages that it offered to the designer. The military industry could not ignore this development and soon became a major user of composites, especially in the aerospace field.

Today's mobile assault bridges are typically very heavy to support tank crossings. But with the advent of new composite materials that are both lightweight and strong, US defense agencies are funding development of an expandable large-span composite assault bridge that can be easily transported via truck or plane to a location and then delivered by tank. Jacobs School of Engineering is also developing on-site manufacturing techniques for such bridges to minimise the transport of materials, and working on technology that can enable bridges to be easily dropped in place by helicopter. Let us

therefore first understand what these advanced composite materials are?

7.10.1 What's a Composite?

Most of the products we see everyday are made from monolithic materials. That means the individual components consist of a single material (an unreinforced plastic), or a combination of materials that are combined in such a way that the individual components are indistinguishable (a metal alloy). Composite materials, on the other hand, consists of two or more materials combined in such a way that the individual materials are easily distinguishable. A common example of a composite is concrete. It consists of a binder (cement) and a reinforcement (gravel). Adding another reinforcement (rebar) transforms concrete into a three-phase composite.

The individual materials that make up composites are called constituents. Most composites have two constituent materials, a binder or matrix, and a reinforcement. The reinforcement is usually much stronger and stiffer than the matrix and gives the composite its good properties. The matrix holds the reinforcements in an orderly pattern. Because the reinforcements are usually discontinuous, the matrix also helps to transfer load among the reinforcements.

Matrix materials are usually some type of plastic, and these composites are often called reinforced plastics. There are other types of matrices, such as metal or ceramic, but plastics are by far the most common. There are also many types of plastics, but a discussion of these is beyond the scope of this monograph. Suffice it to say for now that the two most common plastic matrices are epoxy resins and polyester resins.

Composite materials are available as plies or lamina. A single ply consists of fibres oriented in a single direction (unidirectional) or in two directions (bidirectional; for example a woven fabric). Composite properties are best in the direction of the fibres. Because most structures are not loaded in a single direction, even though one direction may dominate, it is necessary to orient fibres in multiple directions. This is accomplished by stacking multiple plies together. Such a stack is called a laminate.

The most efficient composites have most of their fibres oriented in the primary load direction, and just enough fibres oriented in the other directions to carry secondary loads and hold the structure together. Efficiency means, both low weight and low cost, therefore, fibre which don't carry much load could probably be removed.

7.11 MEMBERS IN COMPRESSION

Based on the type of chemical reaction (polymerisation) that links the molecules together, plastics are classified as either thermoplastics or thermosets. The microstructures of these plastics

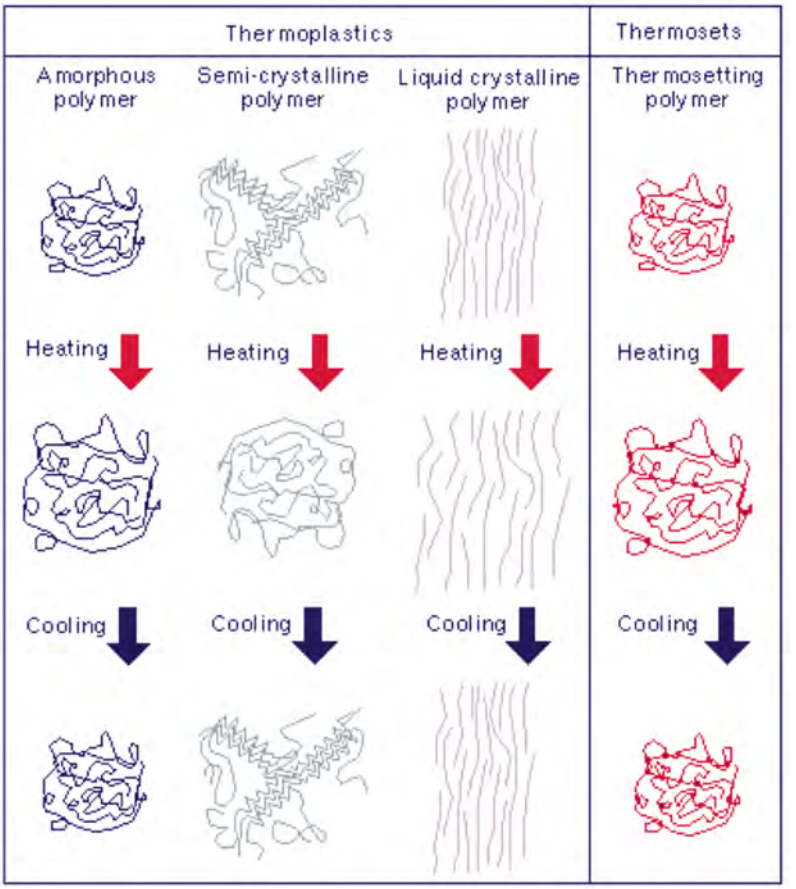


Figure 7.3. Microstructure of various plastics and effect of heating and cooling during processing.

and the effects of heating and cooling on the microstructures are shown in Fig. 7.3. Other classes include elastomers, copolymers, compounds, commodity resins, and engineering resins. Additives, fillers, and reinforcements are other classifications that relate directly to plastics properties and performance.

After having a quick look at some of the basics for composites, let us see how Lockheed Martin started working on a composite bridge that will have a dual use. The bridge project is part of a government industry dual use programme to foster the product development strategy that, in this instance, seeks to improve the health of the nation's advanced materials industrial base by developing the use of composite materials for civil infrastructure renewal. In just 18 months, the Lockheed Martin team designed, analysed, fabricated, assembled, and tested a short-span (less than 140 ft long) traffic-bearing fibre glass-polymer composite bridge. The design emphasized low manufacturing costs and component quality that could be consistently delivered at competitive prices. The design approach involved combining aerospace knowledge of composite materials and structures with affordable manufacturing and assembly methods used

Figure 7.4. Transportation of composite components of a civil bridge.

Figure 7.5. Assembled lockheed bridge bay as technology demonstrator.

in commercial and civil practice. A short-span bridge was designed because that size represents 70 per cent of the total bridge market, including military bridges. The bridge was fabricated in just five weeks by two local fibre glass companies. There are many agencies world over who have started developing composite bridges for civil infrastructure. This is particularly important, since once such bridges find widespread applications, the demand for the fibre and resin will be substantial. This will bring down the cost of these new materials. The Lockheed concept and some other bridges for civilian application developed in the USA are covered by the Figs. 7.4 and 7.5.

7.11.1 Design – Comparison with other Structural Materials

Due to the factors described under the heading Design Philosophy, there is a large range of mechanical properties that can be achieved with composite materials. Even when considering one fibre type on its own, the composite properties can vary by a factor of 10 with the range of fibre contents and orientations that are commonly achieved. The comparisons that follow therefore show a range of mechanical properties for the composite materials. The lowest properties for each material are associated with simple manufacturing processes and material forms (e.g., spray lay-up glass fibre), and the higher properties are associated with high technology

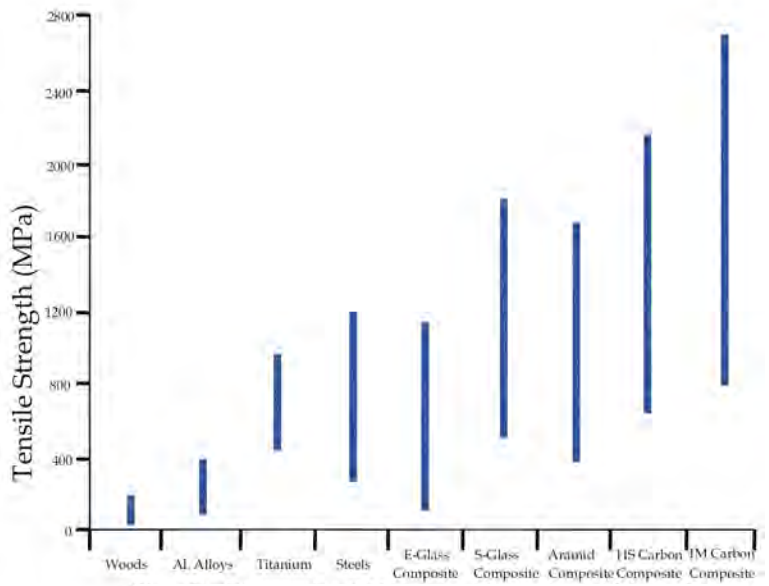


Figure 7.6. Tensile strength of common structural materials.

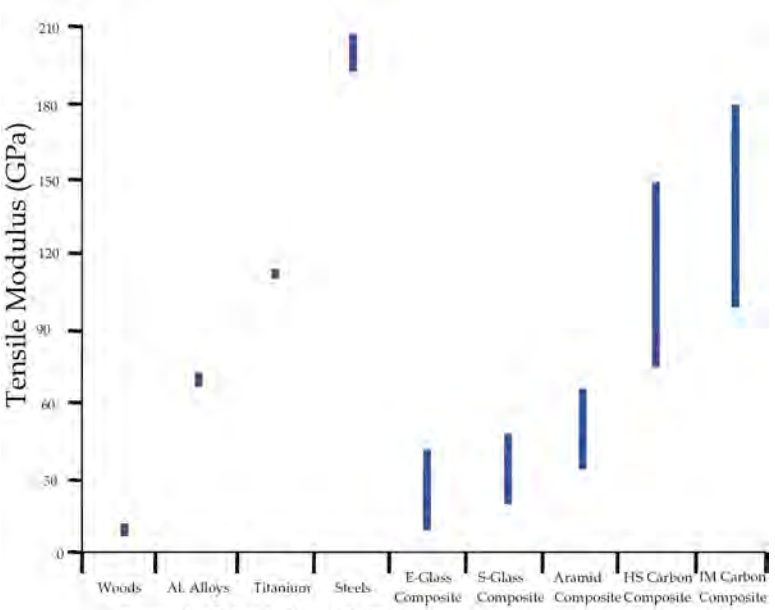


Figure 7.7. Tensile modulus of common structural materials.

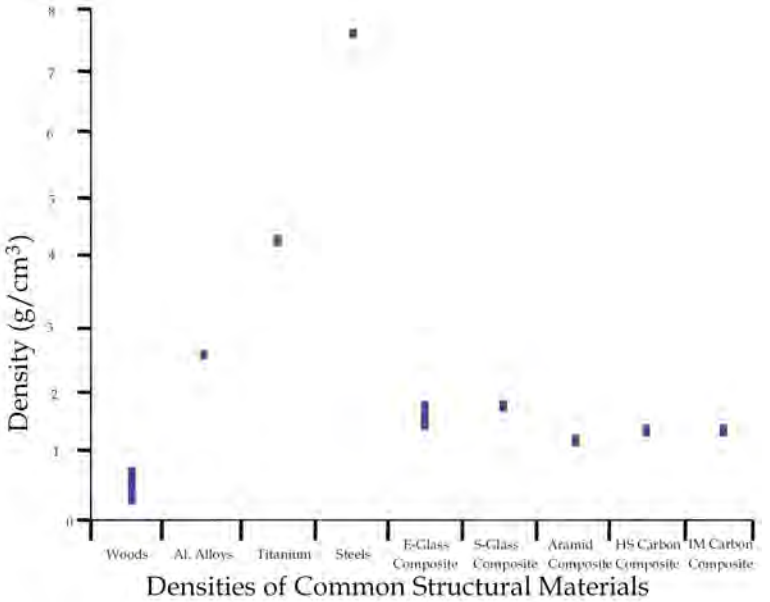


Figure 7.8. Densities of common structural materials.

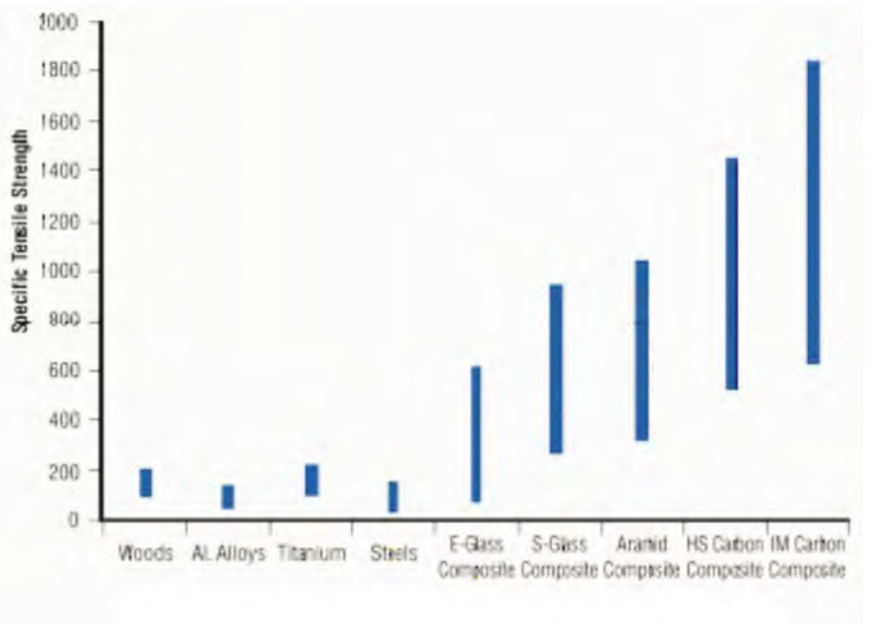


Figure 7.9. Specific tensile strength of common structural materials.

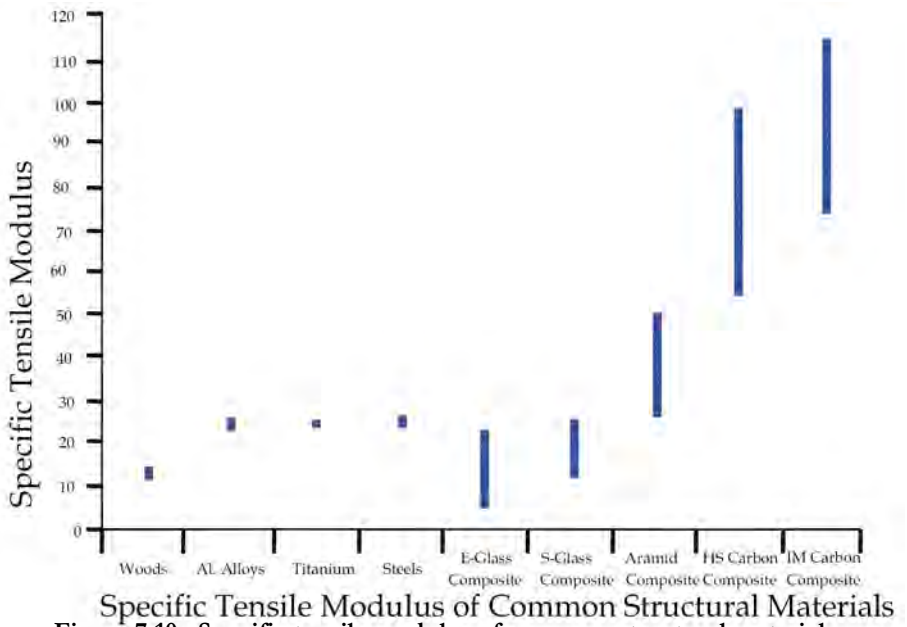


Figure 7.10. Specific tensile modulus of common structural materials.

manufacture (e.g., autoclave moulding of unidirectional glass fibre prepreg), such as would be found in the aerospace industry. For the other materials shown, a range of strength and stiffness (modulus) figures is also given to indicate the spread of properties associated with different alloys, for example.

Figures 7.6 to 7.10 clearly show the range of properties that different composite materials can display. These properties can best be summed up as high strengths and stiffnesses combined with low densities. These are the properties that give rise to the characteristic high-strength and stiffness to weight ratios that make composite structures ideal for so many applications. This is particularly true of applications which involve mobile systems, such as cars, trains and aircraft, since lighter structures in such applications play a significant part in making these applications more efficient.

The strength and stiffness-to-weight ratio of composite materials can best be illustrated by the Fig. 7.9 and 7.10 that plot specific properties. These are the result of dividing the mechanical properties of a material by its density. Generally, the properties at the

higher end of the ranges illustrated in the previous graphs are produced from the highest density variant of the material. The spread of specific properties shown in the graphs takes this into account.

Advanced composites were one of six such technologies chosen for initial analysis by a consensus of the Department of Commerce (Bureau of Export Administration), Department of Defense, and the White House Office of Science and Technology Policy. The other assessments cover advanced ceramics, artificial intelligence, flexible computer integrated manufacturing, optoelectronics, and superconductivity. While the Department of Defense has deemed these technologies essential to the development of the next generation of weapon systems, they are also crucial to the nation's ability to compete in the global economy.

An extensive survey of the industries engaged in design, research and development of advanced composites in America was carried out and a vast majority of information provided by companies who are users of advanced composites materials pertained primarily to defence uses. Almost all respondents, whether producer or user of advanced composites, reported supplying various domestic weapon systems: 34 different military aircraft systems were identified; 24 missile and rocket systems; and 16 other military and space systems. This is in contrast to advanced composite industries of other countries, particularly those in Asia (primarily Japan), where commercial uses are more predominant than defence uses.

Today's mobile assault bridges are typically very heavy to support tank crossings. But with the advent of new composite materials that are both lightweight and strong, defense agencies are funding development of an expandable large-span composite assault bridge that can be easily transported via truck or plane to a location and then delivered by tank.

Jacobs School structural engineers are working through a contract with the Defense Threat Reduction Agency (DTRA), US, to investigate effective measures to retrofit US embassies and critical

Figure 7.11. The prototype sub-assembly of a composite bridge under testing at the UCSD.

structures worldwide against blast loads. They are using composite overlays, originally developed by UCSD faculty to protect buildings from earthquakes as shown in Fig. 7.11. The material is about as thin as a cotton shirt, and is made of carbon threads that are precisely woven to increase the strength and flexibility of a structure. The overlays are applied like wall paper on the walls, floors or columns of a structure. The composite overlays allow the building to absorb horizontal forces and prevent key structural components from failing. Approximately 2,000 hospitals, parking garages, and commercial and residential buildings worldwide have been seismically retrofitted using this technique.

7.12 CONCURRENT ENGINEERING AND APPLICATION OF INFORMATION TECHNOLOGY

The increasingly changing scenarios in tecnology cannot be ignored by the military bridge developers. There have been regular attempts to pass the technology benefits to the customer by improved

performance, reduced costs, and shrinking development times. In the commercial world, competition is another reason for bringing these technologies in. It cannot be said that the military market is in any way different.

Concurrent engineering, quality function deployment, CAD/CAE/PDM/ERP are all excellent tools and philosophies to help organise the design, manufacture and process data before even thinking of writing a spec for managing what data to move, and how to move it. Taking the time to examine and reengineer the processes is the first step regardless of what automation we can write into our data delivery schemes, which finally get converted into bridge delivery systems.

An interdisciplinary research laboratory CERC, West Virginia University, was originally established by the Defense Advanced Research Projects Agency (DARPA) as the cornerstone of the DARPA Initiative in Concurrent Engineering (DICE), a university/industry consortium formed to develop innovative computer technologies and information management methods to support concurrent engineering teams. Through the DICE project, CERC has educated tens of thousands of people from industry, government, and academia about the benefits of using concurrent engineering and the collaboration technologies that enable it. Competition in both commercial and defence sectors is providing ever increasing pressure for more cost effective engineering designs. The implementation of concurrent engineering broadens the scope of potential trade off's to the entire product life cycle. As a result, concurrent engineering places even greater demands on the ability to effectively accomplish these trade offs. CERC defines concurrent engineering as follows: concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. Developer has to consider all elements of the product life cycle from conception through disposal including quality, cost, schedule and user satisfaction

PDMs typically have the ability to create parts (items) and manage the relationship between these and other parts (product

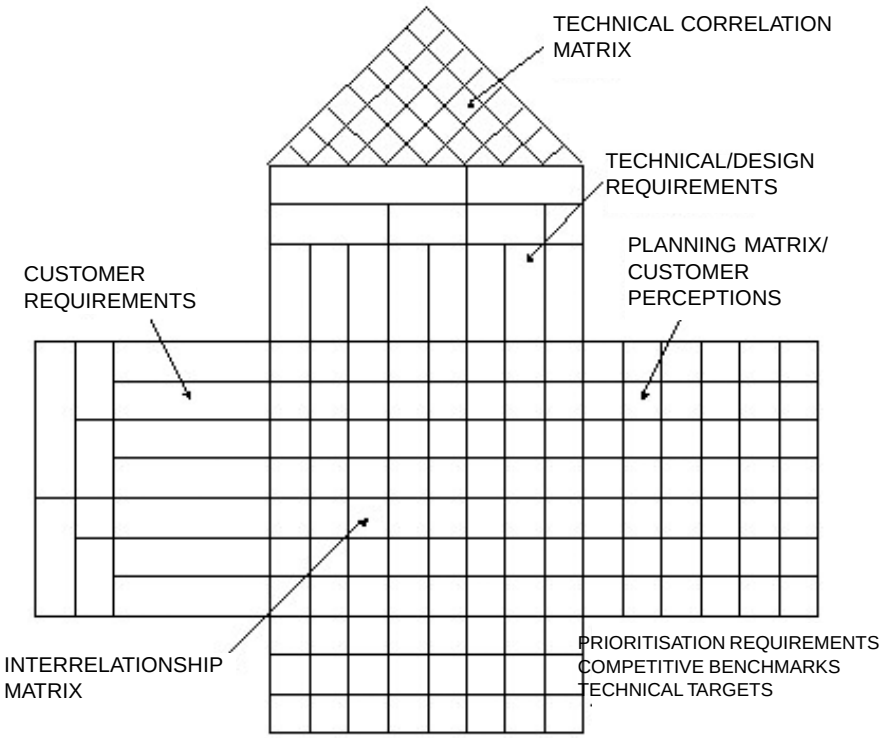


Figure 7.12. A typical representation of the house of quality.

structure). This structure goes well beyond the traditional bill of material (BOM) requirements that manufacturing resource planning (MRP II) requires in that it captures all of the data required to build, test, inspect, etc. a product. For this, only the BOM – the basic structure common to both of these systems will be addressed. Routings, shop order data, operations, workcentres and other processes, although a consideration for the PDM/MRP II link, are not covered in depth in this monograph.

7.12.1 Understanding Customer Requirements

Quality function deployment (QFD) is a quality system that implements elements of systems thinking (viewing the development process as a system) and psychology (understanding customer needs,

what value is, and how customers become interested, choose, and are satisfied, etc.). As a quality method, it is also an example of good knowledge/epistemology (How do we know the needs of the customer? How do we decide what features to include? and, to what level of performance?)

In capturing the voice of customer analysis, it is important to adopt methods that identify which customers are most important to the success of the project, going to the gemba to observe them interacting with the product or service, and carry out detailed analysis to see and hear the hidden and exciting requirements. Good QFD will do this particularly for existing products undergoing upgrades.

The house of quality matrix is the most recognised form of QFD. Figure 7.12 shows a typical house of quality representation. It is utilised by a multidisciplinary team to translate a set of customer requirements, drawing upon market research, and benchmarking data into an appropriate number of prioritised engineering targets to be met by a new product design. There are many slightly different forms of this matrix and this ability to be adapted to the requirements of a particular problem or group of users forms one of its major strengths. The general format of the house of quality is made up of six major components which are completed in the course of a QFD project:

(a) Customer requirements (hows) – a structured list of requirements derived from customer statements.

(b) Technical requirements (whats) – a structured set of relevant and measurable product characteristics.

(c) Planning matrix – illustrates customer perceptions observed in market surveys. Includes relative importance of customer requirements, company and competitor performance in meeting these requirements.

(d) Interrelationship matrix – illustrates the QFD team's perceptions of interrelationships between technical and customer requirements. An appropriate scale is applied,

illustrated using symbols or figures. Filling this portion of the matrix involves discussions and consensus building within the team and can be time consuming. Concentrating on key relationships and minimising the numbers of requirements are useful techniques to reduce the demands on resources.

(e) Technical correlation (roof) matrix – used to identify where technical requirements support or impede each other in the product design. Can highlight innovation opportunities.

(f) Technical priorities, benchmarks, and targets – used to record the priorities assigned to technical requirements by the matrix, measures of technical performance achieved by competitive products and the degree of difficulty involved in developing each requirement. The final output of the matrix is a set of target values for each technical requirement to be met by the new design, which are linked back to the demands of the customer.

7.13 CONCLUSION

This chapter attempts to give an broad overview of the technologies that are relevant to the military bridging equipment. It covers from the materials to design and new management techniques that are relevant to any new product development. The subjects are covered cursorily and there is no intention to mean that this monograph gives a comprehensive coverage of any of these. It can, however, provide a useful guide to get an introduction to these technologies. Thus, the interested reader may be directed to the sources where he can get additional material on respective subjects.

CHAPTER 8

MILITARY BRIDGE CLASSIFICATION SYSTEM

8.1 BACKGROUND

The World War II saw a spectacular proliferation of battle tanks in the European theater. As the MBT brought a revolution in land warfare, as demonstrated by the German Blitzkrieg, the British tanks were quick to follow. In the resulting race and competition between technologies, the obstacle-crossing capabilities became suddenly important for ensuring mobility of the advancing tank columns. The Bailey bridge made historic contributions to the allied military effort. Suddenly a need was felt to establish a relationship between the load-carrying capability of the bridging equipment and the weight and dimensional attributes of the wheeled and tracked vehicles that were already in use and those which were rapidly introduced in-service from time to time. The British War Office published *Military Engineering*, Vol III, 1941 to introduce for the first time the military bridge classification system. Being compiled in a hurry, it had several shortcomings. These were taken care of soon after the end of World War II. The British War Office's publication, issued in 1957, titled *Military Engineering*, Vol III, 1957 incorporated several modifications which could take care of the new developments in the field of military vehicles and bridges up to 1957. After the formation of the NATO, the interoperability requirements necessitated a common standard, which was issued in the 1970s in the form of a standard agreement – Stanag 2021. This standard is being used today for classifying both military vehicles and bridges.

This chapter describes the basic objective of adopting a unified military load classification system and gives detailed tables in a comprehensive manner to help the designers and users of both the military and civilian bridges and vehicles.

8.2 INDIAN ENVIRONMENT

The Indian army has a very wide variety of military bridging equipment and vehicles in its inventory. The sources for these are partly Indian and partly from foreign. The overseas sources from whom the equipment is imported includes a broad mix of erstwhile Soviet countries, as well as a few NATO countries. It is possible to classify any vehicle either as per the earlier system (1957) or the newly introduced NATO standard system. The resulting classification number may not be the same. The two numbers thus obtained cannot also be compared by the ratio or difference considerations that are normally used in mathematical methods.

In the case of equipment bridges, however, the classification numbers are considered at the design stage itself since the equipment bridges are designed for the loading conditions imposed by the hypothetical loads and not the actual in-service loads. Therefore, if the design details are not made available, it is not easy to determine the exact load-carrying capacity of the bridge wrt the standard/ hypothetical vehicles or any new vehicle that will be brought into service in the future. If however, only one standard method of bridge classification is used, as in the case of NATO, this situation is averted since it is clearly known as to what loads that bridge can safely withstand.

The confusion becomes clear when the capacity of the Soviet block bridging equipment is considered. Such equipments are designated not by the standard bridge class number but by weight such as 50 tonne bridge. This implies that a tank weighing up to 50 tonnes can negotiate the bridge. However, the stresses that are induced due to a moving load are not simply governed by the gross weight. More important is to see how this load is distributed over the length of the track. The bending moments and shear forces induced in the structure

are determined by such a distribution and not by the gross weight. The latest NATO system takes into account such effects by providing tables, graphs, and curves for the hypothetical vehicles. This becomes a common basis for comparing the structural implications of the imposed loads and the designed load-carrying capacity of the bridge. To a layman, it may become quite intriguing to see how a NATO–MLC 60 bridge is required for the negotiation of Soviet 50 tonne tank whereas the Soviet 50 tonne bridge is adequate for the same purpose.

The Indian army has bridging equipment and wheeled/tracked vehicles from both east European and western sources, the battlefields differ considerably in their nature ranging from coastal areas of Gujarat to the high altitudes and hilly terrains of northern Himalayas and the riverine terrain on the east. The army therefore needs to be prepared for desert warfare, mountain warfare, and high altitude warfare. In each type of warfare, the main weapon is different and the obstacle patterns are also quite diverse. Bailey bridge, which was successfully deployed in the European theaters during the World War II, continued in service with the Indian army till early 1970s. Its versatility to have different configurations for different crossing needs was of great advantage during the World War II. In the Indian context, it was also extensively used in the Bangladesh war, which was rightfully known as the Engineers War. However, with changing battlefield scenarios, Bailey bridge could not serve the operational needs of the modern warfare.

Similarly, there was a vast difference between the mobility requirements of one theater from the other. Thus, the MBT assumed great importance for the western theater in India; the mountain warfare of the east demanded lighter wheeled trucks to carry troops and guns. Willy's jeep, Nissan Jonga and *Shaktiman* became India's most commonly used wheeled vehicles immediately after 1962 Indo-China conflict. The hypothetical vehicles included in the NATO bridge classification system differed considerably in loading and dimensional characteristics of these actual vehicles in service. To adopt NATO system straightaway as Indian standard bridge

classification system would have caused a few problems for working out load classification requirement for Indian bridging systems. This was particularly important since India had capacity to develop bridging systems indigenously and a general staff policy statement issued in 1969 enumerated different bridging systems that were assumed to be required for the Army's operational readiness for the future. To spell out the requirements for forward locations in hills, where only jeeps or jongas could operate, a new class number to match the characteristics of these vehicles was required. Similarly, for light and medium duty trucks, the *Shaktiman* (GS-3 tonner) became the workhorse of the Indian army. A special class number to match the features of this vehicle was therefore considered necessary. NATO's standard class numbers for these vehicles were MLC 4, 8, 12... while the actual interpolated class number of the above-mentioned vehicles were 3 and 9. The Indian army therefore considered it prudent to introduce new class numbers, class 3 (lesser than standard class 4) and class 9 in between NATO's standard class numbers 8 and 12. This was carried out by bringing out the Indian edition of the War Office, UK, publication titled Military Engineering Vol III, 1957 in the year 1968. The Indian edition was really a reprint of the original handbook with the only difference that the charts and tables showing hypothetical vehicles were replaced by modified charts, just to include the two additional hypothetical vehicles, and correspondingly the bridge class numbers designated as class 3 and class 9. While doing so, all other load class numbers were affected since the hypothetical vehicles were altogether different from the NATO standard. This mistake, or rather anomaly, inadvertently crept in causing utter confusion about the load class numbering system. The other point that was missed was that there was no mention anywhere in the Handbook that such changes were made. On the contrary, the Indian edition mentioned that the Handbook was a reprint of the War Office, UK, publication. To rectify this anomaly, *Appendix B* has been introduced to suggest the adaptation of the NATO system (Stanag 2021) to meet the specific Indian requirement of light vehicles and trucks.

The civil bridges in India are governed by the loading standards and codes prescribed by the Indian Roads Congress (IRC), New Delhi. For tracked vehicles (such as battle tanks) and load trains beyond a particular loading limit (such as tank transporters), IRC gets the input from the Ministry of Defence. However, there are certain deviations from the actual practice. The situation has been created by allowing some inaccuracies in documentation. New vehicles that are introduced by the manufacturers have no checks regarding compliance to the requirements of the military load classification system. Although the civil bridges rely very much on a liberal factor of safety and frequent overloading of the civil trucks is a common phenomenon, the effects of improper communications between the design agencies and the controlling agencies could result in damage to short-span bridges and culverts, which are designed for maximum axle loads that are governed by the military code and practices. Proper coordination, clearance by a certifying authority after physically carrying out inspection, and wider publicity amongst the bridge designers and state authorities could be the possible solutions for the future. The case will be amply clear if the BEML tank transporter having axle loads in excess of allowable 20 tonne is examined. This tractor–trailer combination is likely to damage many culverts just because the single allowable axle load is exceeded.

8.3 THE SYSTEM AND ITS APPLICATION

Military Engineering ,Vol III, 1957 identifies and elaborates on the rationale behind the formulation of a common system, the NATO standard agreement Stanag 2021 only converts it into metric system and adds or changes a few clauses/parameters for standardisation. However, the basis of the system remains unaltered.

The basis of the system is that each military vehicle and bridge carries a load class number. The vehicle may cross the bridge if the number assigned to it is not greater than the bridge class number. This ensures that no member of the bridge is overstressed beyond the capacity for which it is designed.

Military bridges are designed against a very low factor of safety as compared to the civilian bridges. Various reasons are:

(a) The traffic on a military bridge is strictly controlled.

(b) A failure due to overloading of the bridge is accepted. The Commander, after considering all implications, may allow a higher class vehicle to negotiate a lower class bridge under caution crossing or risk crossing procedures.

(c) The equipment bridge in the prototype stage is subjected to loading trials to validate the design. Strict quality control is observed during manufacturing.

(d) Maintenance and training of the operators is periodically carried out as a laid down procedure.

(e) Designing the bridge against a higher factor of safety than the minimum necessary will make the bridging system itself sub-optimal for its main task due to overweight.

Designing the bridge for standard hypothetical vehicles and as per the parameters stipulated in the procedure is therefore the best way to ensure that the bridge is adequately designed for the current operational conditions as well as for the new wheeled or tracked vehicles that may get introduced into service in the future.

Adoption of the NATO standard agreement Stanag 2021 by all countries will ensure that any bridging system in the world can be used for negotiating any vehicle coming from any worldwide source. What would be needed in that case is that the bridging equipment is classified by one standard method and all the wheeled and tracked vehicles also are given standard bridge class numbers as per the same method. As far as India is concerned, the following action is needed:

(a) Official acceptance of the standard method for bridge classification to be promulgated by an executive order taking both the Ministry of Defence and the Ministry of Surface Transport into confidence. The authority to classify, certify, and verify should also be clearly stated in these orders.

(b) Military Engineering, Vol III, 1957 reprinted as an Indian edition in 1968 should be superceded by the latest version taking into account all the developments that have taken place over the last 50

years. The recommended military load classification system and its application for the Indian army and civilian code of practice is given as *Appendix B*. Apart from the chapter on bridge classification, other contents in respect of mine warfare, reconnaissance, and surveying, etc., should also be reviewed and revised wherever necessary. Wherever possible, global standards and procedures should be adopted to facilitate interoperability.

(c) Reclassification of the existing equipment bridges may be carried out as per the accepted standard if the same is not provided by the designer/manufacturer. If sufficient information is not available, an expert committee should examine the issue and suggest measures to accurately determine the bridge classification number for such equipment.

(d) Once the physical dimensions and permissible axle loads are known, assigning the load classification number to military vehicles will be a straightforward job. For civilian vehicles, which can also negotiate the bridges in case of emergencies, proper care should be taken for possible overloading the vehicle beyond permissible limits.

APPENDIX B

THE MILITARY LOAD CLASSIFICATION SYSTEM AND ITS APPLICATION FOR INDIAN ARMY AND CIVILIAN CODES OF PRACTICE

B1 INTRODUCTION

The military bridges compared to the civil bridges, are designed with a low factor of safety to achieve minimum weight for easy transportation and erection. In view of this, it is of utmost importance that the military bridge should not be overloaded. That is to say, a vehicle which may cause failure of the bridge should not be allowed to cross the bridge. It is also essential that the military bridge is not overdesigned since such conservative designs will result in reduced performance and operational efficiency. To ensure this, the military load classification system has been evolved in which the bridge, rafts (including their landing stages), and the vehicles are given classification number indicating the relationship between the load-carrying capacity of the bridge or raft (including their landing stages) and the effect produced by the vehicle.

Military bridge classification system was introduced during the World War II. The system was described in Military Engineering Vol III, 1941 published by The War Office, London. This system amounted to finding the equivalent bridge weight carrying capacity from certain parameters of actual vehicle. Initially, the system catered for load classes up to only CL18. It was, however, updated from time to time to cater for heavier vehicles. This system had many shortcomings. More

importantly, the system did not correlate the effect of bending moment and shear on different bridge spans and the corresponding capacity in terms of the load class number. This limitation was overcome when a completely revised system worked out by Military Engineering Experimental Establishment, Christchurch, UK, (later merged with MVEE) was introduced in 1957. The details of this system are given on Military Engineering, Vol III Bridging Part I (General), 1957 published by The War Office, London. Later on, the NATO countries followed the same system under a specific agreement Stanag 2010. While the NATO countries adopted the system, the same was metricised and certain modifications were made to make it more rational. However, the Indian army, while adopting the system for its own use, made certain changes based on the report of CME. The Indian edition of Military Engineering Vol III, Part I, 1968 included this system without even mentioning that it departed from the NATO standard in many respects. Even though this system adopted the concept of correlation of class number and the effect of bending moment and shear created by the vehicle on the bridge in this system the set of hypothetical vehicles and the resulting bending moments and shear values were totally different from those adopted by the NATO system. Hence it was not possible to correlate the class number computed by this system to that of the internationally accepted NATO system. It was quite intriguing to note that the Indian load class 50 almost amounted to NATO load class MLC 60.

To overcome this anomaly, a revised system has been proposed and is described in the subsequent paragraphs. This system is essentially based on the NATO system with the addition of classes 3, 5, and 9 as standard classes to cover a large number of existing service vehicles with the Indian army, such as jonga/jeep, GS 1t and GS 3 t vehicles. The proposed system was worked out by the author and his colleagues at R&DE (Engrs); but never found acceptance by the services since the underlying problem and the confusion was never appreciated by them. Today, the bridges imported from UK and Germany are classified as per NATO system as no one knows their class number by the CME method. The tank bridges imported from

the erstwhile Soviet Union are similarly designated a number, which represents the approximate weight of the tank that it can carry. The indigenous bridges developed by R&DE (Engrs) however carry the class number as per NATO system, since that is the only way to draw comparisons regarding performance of various bridges produced by different countries. The army Hqrs has also indirectly accepted the reality, which is evident by the GSQRs stipulating NATO load class numbers for development of new generation of bridges.

B2 AIM AND BASIS OF THE SYSTEM

Stresses are induced in the members and joints of a bridge when it is crossed by a vehicle. These stresses must not exceed a certain predetermined safe value if the bridge is to carry the vehicle without being overloaded, and the risk of failure of the bridge is averted.

The load classification system is designed to prevent a vehicle from crossing a particular bridge, if it would induce in that bridge stresses exceeding the safe values.

The basis of the system is that each vehicle and bridge carries a load class number. If the vehicle class number is less than or equal to the bridge class number, the vehicle may cross that bridge. If, however, it is higher, the vehicle must not cross, but must be diverted. Under exceptional operational conditions this prohibition may be lifted on the specific orders of the competent military authority in the operation zone, who will have to balance the effect of overloading the bridge against the tactical importance of the crossing. The civil authorities in areas under their control may also lift it.

The above remarks also applies to rafts and their landing stages and to the embarking of vehicles on them.

B3 GENERAL DESCRIPTION OF THE SYSTEM

The load effect produced by a series of hypothetical vehicles are used to define a set of load class numbers, which form the link between the carrying capacity of the bridge and the effect produced on it by real vehicles.

Each load class is defined by a UBM (unit bending moment = BM/span) classification curve, a shear classification curve, maximum single-axle and tyre loads, and minimum overall ground contact width. In calculating UBM and shear, no allowance is made for impact effects.

The UBM and shear curves are produced by calculating the maximum values of UBM and shear imposed on spans up to 100 m by a range of successively heavier hypothetical vehicles at 30.48 m spacing. The load classification curves so produced show a series of successfully higher standard load classes denoted by successively higher numbers.

A vehicle is classified by comparing the curves of maximum UBM and shear which a convoy of such vehicle imposes on spans up to 100 m with the classification curves for the standard load classes. The vehicle class number is obtained by interpolation and is assigned the nearest whole number.

A bridge is classified by giving it a number equal to that of the highest standard load class whose effects (UBM, shear, axle load, etc.) it can safely withstand for an unlimited number of uses. Rafts and landing stages are classified in a similar manner but in addition buoyancy is taken into account.

Thus, vehicles are classified by giving them a number, which is independent of any particular bridge that they may cross. Similarly, bridges are classified or designed for a standard load class and not for any specific vehicle.

B4 SPACING OF VEHICLES IN CONVOY

The load classification system includes the new ruling that all vehicle must cross bridges at a spacing of not less than 30.48 m between the rear axle of the leading vehicle and the front axle of the following vehicle in the cases of wheeled vehicles, or with 30.48 m between the equivalent points of ground contact in the case of tracked vehicles.

B5 DETAILS OF SYSTEM

The following list of tables, graphs, and charts cover the detailed values for UBM and shear for standard load classes. The details of the hypothetical vehicles, tables for UBM and shear for load classes

up to MLC 150, the UBM, and shear curves and width correction factors are common for the suggested Indian system and the NATO standard. Only difference is that of addition of MLC 3, MLC 5, and MLC 9 in the Indian system. The data sheet and figures of the curves are therefore not repeated for the two systems and are given along with this Appendix of Chapter 8.

Table 8.1. Hypothetical vehicles for military load classification
Table 8.2. UBM chart for classes up to MLC 30 (wheeled vehicles)
Table 8.3. UBM chart for class MLC 30–150 (wheeled vehicles)
Table 8.4. Shear chart for classes up to MLC 30 (wheeled vehicles)
Table 8.5. Shear chart for classes up to MLC 30–150 (wheeled vehicles)
Table 8.6. UBM chart for classes up to MLC 30 (tracked vehicles)
Table 8.7. UBM chart for class MLC 30– 50 (tracked vehicles)
Table 8.8. Shear chart for classes up to MLC 30 (tracked vehicles)
Table 8.9. Shear chart for classes up to MLC 30–150 (tracked vehicles)
Table 8.10. Vehicle width adjustment factor
Table 8.11. Data sheet for classification of new vehicle

Standard load class have been established and numbered as under:

MLC 3	MLC 4	MLC 5	MLC 8	MLC 9
MLC 12	MLC 16	MLC 20	MLC 24	MLC 30
MLC 40	MLC 50	MLC 60	MLC 70	MLC 80
MLC 90	MLC 100	MLC 120	MLC 150	

Load classes MLC 3, MLC 5, and MLC 9 are introduced as additional load classes to suit the Indian army's requirements for vehicles in-service.

The above table includes three additional load class number that are recommended for adoption for the Indian system without affecting the standard load class number adopted by NATO countries. This is to accommodate the sizeable number of MLC 3, MLC 5, and MLC 9 vehicles that are already in service with the Indian army.

For each load class a hypothetical tracked vehicle and a hypothetical wheeled vehicle have been created. These vehicles are not arbitrary, but represent average service vehicles. Their weights increase with increasing load class numbers.

Each vehicle is precisely specified as to weight, width over tracks, track width, track length, axle loads, and axle spacing.

As the local loading on bridge decking system and not overall bending moment effect, may be critical (specially for short spans), the maximum single-axle loads, tyre loads and tyre pressures, minimum wheel spacing and tyre sizes, are specified for each class. This enables the effect of the actual vehicle to be checked when it differs in design from the hypothetical vehicle of the load class in question.

B6 THE CLASSIFICATION TABLES AND CURVES

The enclosed Tables 8.2 to 8.9 show the maximum values of UBM and shear imposed on spans up to 100 m by the following loads of each class (a) Wheel loads W : The hypothetical wheeled vehicle singly or in convoy at 30.48 m spacing, or the axle load, whichever is greater, (b) Track loads T : The hypothetical tracked vehicles singly or in convoy at 30.48 m spacing, whichever is great.

Using corresponding values from Tables 8.2 to 8.9 a UBM classification curve and a shear classification curve are drawn for each load class. The classifications curves are shown in Figures 8.1 to 8.12.

For each load class up to and including 30, the classification curves represent the effect of either the wheel or track loads, whichever is greater at the span in question. For short spans, the single axle load gives higher values, for longer spans the wheeled or tracked vehicle give higher values.

For load classes 40-150, the classification curves for wheeled and tracked vehicles show marked differences in effect and therefore the wheel and track load UBMs and shears are plotted as separate classification curves for each of these classes.

Vehicles narrower or wider than the hypothetical vehicles or corresponding class have their classification adjusted by means of the vehicles width factor shown in Table 8.10. This gives the per cent increase or decrease in classification number per cm of width deficiency or excess.

Table 8.1. Hypothetical vehicles for military load classes

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXIAL LOADS & SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TYRE SIZE (mm) OF CRITICAL AXLES			MAX. TYRE LOAD AND MIN. TYRE SIZE (mm)
3		2.91 Ton 2.20 1.42 0.89	1.42	Single Axle: 152X400 1.40			0.71 Tonnes on 152X406
4	3.63 Ton 0.30 1.83 1.83	4.08 Ton 1.22 2.44 1.59 1.59 0.91	2.27	Single Axle: 190X508 1.83 Bogie Axle:190X508	Single Axle: 203X508 0.36 0.36 1.83 Bogie Axle: 152X406		1.13 Tonnes on 190X508
5	4.53 Ton 0.30 1.83 1.83	4.30 Ton 2.80 2.93 1.37	2.93	Single Axle: 210X508 1.60			1.46 Tonnes on 210X508
8	7.26 Ton 0.30 1.98 1.98	8.16 Ton 1.22 3.05 2.72 2.72 2.72	4.99	Single Axle: 305X508 2.08 Bogie Axle:229X508	Single Axle: 210X508 0.48 0.46 2.08 Bogie Axle:190X508		2.49 Tonnes on 305X508
9	8.16 Ton 0.30 2.36 1.98	9.03 Ton 4.20 6.20 2.83	6.20	Single Axle:210X508 1.70	Single Axle: 210X508 0.36 0.36 1.70		3.10 Tonnes on 210X508
12	10.89 Ton 0.30 2.74 2.03	13.61 Ton 3.66 1.22 3.05 1.81 4.54 4.54 2.72	7.26	Single Axle: 356X508 2.13 Bogie Axle:229X508	Single Axle: 254X508 0.58 0.46 2.13 Bogie Axle: 190X508		4.54 Tonnes on 356X508

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXIAL LOADS & SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TYRE SIZE (mm) OF CRITICAL AXLES			MAX. TYRE LOAD & MIN.TYRE SIZE (mm)
16	14.51 Ton, 0.30, 2.74, 2.13	16.78 Ton; 3.66, 1.22, 3.05; 2.27, 5.90, 5.90, 2.72	9.07	Single Axle: 406X610; 2.29; Bogie Axle:356X508	Single Axle: 305X508; 0.66, 0.53; 2.29; Bogie Axle: 229X508	Single Axle: 305X508; 2.29; Bogie Axle: 229X508	4.54 Tonnes on 406X610
20	18.14 Ton, 0.41, 2.74, 2.44	21.77 Ton; 3.66, 1.22, 3.05; 2.72, 7.71, 7.71, 3.63	9.98	Single Axle: 457X610; 2.44; Bogie Axle:356X610	Single Axle: 305X508; 0.66, 0.66; 2.44; Bogie Axle: 305X508	Single Axle: 305X508; 2.44; Bogie Axle: 305X508	4.99 Tonnes on 457X610
24	21.77 Ton, 0.46, 2.74, 2.54	25.40 Ton; 3.66, 1.22, 3.05; 2.72, 9.07, 9.07, 4.54	10.89	Single Axle: 457X610; 2.44; Bogie Axle:406X610	Single Axle: 356X508; 0.81, 0.66; 2.44; Bogie Axle: 305X508	Single Axle: 356X508; 2.44; Bogie Axle: 305X508	5.44 Tonnes on 457X610
30	27.72 Ton, 0.46, 3.35, 2.54	30.84Ton; 3.66, 1.22, 3.05; 5.44, 9.98, 9.98, 5.44	12.25	Single Axle: 457 x 508; 2.44; Bogie Axle: 406 x 610	Single Axle: 356 x 508; 0.81, 0.66; 2.44; Bogie Axle: 305 x 508	Single Axle: 356 x 508; 2.44; Bogie Axle: 305 x 508	6.12 Tonnes on 457 x 610
40	36.29 Ton, 0.56, 3.66, 2.94	42.64Ton; 4.88, 1.22, 3.66; 12.70, 11.79, 11.79, 6.35	15.42	Single Axle: 533 x 610; 2.54; Bogie Axle:457 x 610	Single Axle: 356 x 610; 0.81, 0.81; 2.54; Bogie Axle: 305 x 508	Single Axle: 356 x 610; 2.54; Bogie Axle: 305 x 508	7.71 Tonnes on 535 x 610
50	45.36 Ton, 0.66, 3.96, 3.25	52.62Ton; 4.88, 1.22, 3.66; 18.14, 13.61, 13.61, 7.26	18.14	Single Axle: 610 x 737; 2.84; Bogie Axle: 533 x 610	Single Axle: 406 x 610; 0.94, 0.81; 2.84; Bogie Axle: 356 x 508	Single Axle: 406 x 610; 2.44; Bogie Axle: 356 x 508	9.07Tonnes on 610 x 737
60	54.43Ton, 0.71, 4.27, 3.35	63.50Ton; 1.22, 4.57, 1.52, 3.66; 11.79, 11.79, 16.33, 16.33, 7.26	20.86		Single Axle: 457 x 610; 1.14, 0.94; 3.25; Bogie Axle:406 x 610	Single Axle: 457 x 610; 3.25; Bogie Axle:406 x 610	9.07Tonnes on 610 x 737

x
x

1	2	3	4	5	6	7	8
		WHEELED VEHICLES					
CLASS	TRACKED VEHICLES	AXIAL LOADS & SPACING	MAXIMUM SINGLE AXLE LOAD	MINIMUM WHEEL SPACING AND TYRE SIZE (mm) OF CRITICAL AXLES			MAX. TYRE LOAD AND MIN TYRE SIZE (mm)
70	63.50 Ton; 0.79; 4.57; 3.51	73.03 Ton; 1.22; 4.57; 1.52; 3.66; 12.70; 12.70; 19.05; 19.05; 9.52	23.13		Single Axle: 457 x 610; 1.04; 0.94; 3.35; Bogie Axle:406 x 610	Single Axle: 457 x 610; 3.35; Bogie Axle:406 x 610	9.07 Tonnes on 610 x 737
80	72.58 Ton; 0.84; 4.88; 3.66	83.46 Ton; 1.52; 5.49; 1.52; 3.66; 14.51; 14.51; 21.77; 21.77; 10.89	25.40		Single Axle: 535 x 610; 1.24; 1.04; 3.51; Bogie Axle: 457 x 610	Single Axle: 535 x 610; 3.51; Bogie Axle: 457 x 610	9.07 Tonnes on 610 x 737
90	81.65 Ton; 0.89; 5.18; 3.81	93.89 Ton; 1.52; 5.49; 1.52; 3.66; 16.33; 16.33; 24.49; 24.49; 12.25	27.22		Single Axle: 533 x 610; 1.24; 1.04; 3.51; Bogie Axle: 457X610	Single Axle: 533X610; 3.51; Bogie Axle: 457X610	9.07 Tonnes on 610 x 737
100	90.72 Ton; 0.94; 5.49; 3.96	104.33 Ton; 1.52; 6.10; 1.89; 3.66; 18.14; 18.14; 27.22; 27.22; 13.61	29.03		Single Axle: 533X610; 1.24; 1.24; 3.66; Bogie Axle:533X610	Single Axle: 533X610; 3.66; Bogie Axle:533X610	9.07 Tonnes on 610 x 737
120	108.86 Ton; 1.02; 6.10; 4.27	125.19 Ton; 1.52; 6.10; 1.89; 3.66; 21.77; 21.77; 32.66; 32.66; 16.33	32.66			Single Axle: 610x737; 3.91	9.07 Tonnes on 610 x 737
150	136.08 Ton; 1.27; 7.32; 4.67	154.22 Ton; 1.89; 6.71; 2.13; 3.66; 29.03; 29.03; 38.10; 38.10; 19.96	38.10			Single Axle: 610x737; 4.06	9.55 Tonnes on 610 x 737

Metric Tonnes

N.B:

1) Single axle tire size shown in Column 5,6 and 7 refer to the maximum single axle loads given in Column 4.
2) Bogie axle tire size shown in Column 5,6 and 7 refer to the maximum Bogie axle loads shown in the diagram in column 3.
3) The maximum tire pressure for all tires shown in Column 8 shall be taken as 690 kN/sq.m (70kp/sq.cm, 100lbs/sq.in)
Actual contact pressure will depend on tire tread pattern and may be as high as 1100kN/sq.m (70 kp/sq.cm, 160lbs/sq.in).
4) First value of tire size refer to nominal overall width of the tire and the second value refers to the rim diameter, both in millimeters.

Table 8.2. UBM values load class 3–30 in tons (spans 4–300 ft) wheeled vehicles

Span	MLC3	MLC4	MLC5	MLC8	MLC9	MLC12	MLC16	MLC20	MLC24	MLC30
4	0.36	0.62	0.78	1.37	1.65	2.00	2.50	2.75	3.00	3.37
6	0.36	0.62	0.78	1.37	1.65	2.00	2.50	2.75	3.00	3.37
8	0.36	0.62	0.78	1.37	1.65	2.00	2.50	2.75	3.00	3.37
10	0.36	0.62	0.78	1.37	1.65	2.00	2.50	2.75	3.20	3.52
12	0.36	0.62	0.78	1.37	1.65	2.00	2.50	2.95	3.47	3.82
14	0.38	0.64	0.78	1.37	1.65	2.00	2.50	3.12	3.67	4.04
16	0.40	0.67	0.78	1.37	1.65	2.00	2.50	3.25	3.83	4.21
18	0.41	0.78	0.82	1.37	1.65	2.00	2.57	3.36	3.95	4.35
20	0.43	0.75	0.88	1.40	1.65	2.12	2.72	3.56	4.30	5.20
25	0.45	0.82	0.92	1.42	1.75	2.25	2.88	3.77	4.45	4.92
30	0.47	0.87	0.95	1.56	1.83	2.42	3.07	4.02	4.75	5.27
35	0.49	0.91	0.97	1.66	1.90	2.58	3.67	4.27	5.04	5.68
40	0.50	0.94	0.99	1.73	1.96	2.73	3.44	4.49	5.28	6.03
45	0.51	0.96	1.00	1.79	2.00	2.84	3.57	4.65	5.47	6.30
50	0.52	0.97	1.01	1.83	2.04	2.93	3.67	4.79	5.62	6.52
55	0.52	0.99	1.02	1.87	2.06	3.01	3.76	4.90	5.75	6.70
60	0.53	1.00	1.03	1.90	2.09	3.07	3.83	4.99	5.85	6.85
70	0.53	1.02	1.04	1.95	2.11	3.17	3.94	5.13	6.02	7.08
80	0.54	1.03	1.06	1.99	2.15	3.24	4.03	5.24	6.14	7.26
90	0.55	1.04	1.07	2.02	2.17	3.29	4.09	5.32	6.23	7.39
100	0.55	1.05	1.07	2.04	2.19	3.34	4.15	5.39	6.31	7.50
110	0.56	1.06	1.07	2.06	2.20	3.38	4.19	5.45	6.37	7.59
120	0.56	1.06	1.07	2.06	2.21	3.41	4.23	5.49	6.43	7.67
130	0.56	1.07	1.08	2.09	2.23	3.43	4.26	5.53	6.47	7.73
140	0.56	1.07	1.08	2.10	2.24	3.46	4.20	5.56	6.51	7.79
150	0.57	1.07	1.09	2.11	2.25	3.48	4.31	5.59	6.54	7.83
160	0.57	1.08	1.09	2.12	2.26	3.49	4.33	5.62	6.57	7.88
170	0.58	1.08	1.09	2.13	2.27	3.51	4.34	5.64	6.59	7.91
180	0.59	1.09	1.09	2.16	2.28	3.52	4.36	5.66	6.61	7.94
190	0.60	1.10	1.11	2.18	2.28	3.53	4.37	5.67	6.63	7.97
200	0.62	1.12	1.17	2.20	2.30	3.54	4.38	5.69	6.65	8.00
210	0.64	1.17	1.21	2.30	2.37	3.55	4.40	5.71	6.67	8.02
220	0.66	1.21	1.25	2.39	2.48	3.62	4.45	5.78	6.75	8.16
230	0.68	1.25	1.29	2.47	2.56	3.77	4.64	6.02	7.04	8.51
240	0.68	1.29	1.33	2.55	2.65	3.91	4.81	6.25	7.30	8.83
250	0.68	1.29	1.34	2.57	2.73	3.71	4.95	6.19	7.43	9.01
260	0.72	1.41	1.36	2.72	2.80	4.16	5.12	6.65	7.77	9.41
270	0.76	1.48	1.44	2.87	2.88	4.27	5.26	6.83	7.98	9.66
280	0.79	1.55	1.51	3.01	3.02	4.38	5.39	7.00	8.18	9.91
290	0.88	1.61	1.78	3.14	3.44	4.59	5.67	7.36	8.60	10.38
300	0.97	1.67	1.87	3.26	3.82	4.81	5.95	7.72	9.01	10.89

Table 8.3. UBM values load class 30–150 in tons (spans 4–300 ft) wheeled vehicles

Span	MLC30	MLC40	MLC50	MLC60	MLC70	MLC80	MLC90	MLC100	MLC120	MLC150
4	3.37	4.25	5.00	5.75	6.37	7.00	7.50	8.00	9.00	10.50
6	3.37	4.25	5.00	5.75	6.37	7.00	7.50	8.00	9.00	10.50
8	3.37	4.25	5.00	5.75	6.37	7.00	7.59	8.00	9.00	10.50
10	3.52	4.25	5.00	5.75	6.37	7.00	7.59	8.00	9.00	10.50
12	3.82	4.51	5.21	5.75	6.58	7.52	8.46	8.47	10.12	10.54
14	4.04	4.78	5.51	6.07	7.08	8.10	9.11	9.26	11.11	11.81
16	4.21	4.98	5.74	6.41	7.47	8.54	9.61	9.90	11.88	12.82
18	4.35	5.14	5.93	6.67	7.79	8.90	10.01	10.42	12.50	13.63
20	5.20	5.34	6.16	6.96	8.18	9.19	10.34	10.94	13.00	14.29
25	4.92	5.54	6.39	7.29	8.51	9.72	10.94	11.62	13.94	15.53
30	5.27	5.99	6.91	7.90	9.28	10.60	0.93	12.75	15.30	17.20
35	5.68	6.31	7.30	8.34	9.83	11.23	12.63	13.61	16.33	18.53
40	6.03	6.91	8.20	9.25	10.70	11.70	13.16	14.25	17.10	19.53
45	6.30	7.45	8.89	10.16	11.74	12.26	13.80	14.75	17.70	20.30
50	6.52	7.88	9.45	10.89	12.57	13.32	14.99	15.43	18.51	20.92
55	6.70	8.23	9.91	11.48	13.25	14.19	15.97	16.62	19.95	21.86
60	6.85	8.52	10.29	11.98	13.82	14.92	16.78	17.62	21.15	23.55
70	7.08	8.98	10.89	12.76	14.72	16.06	18.07	19.20	23.04	26.22
80	7.26	9.33	0.34	13.35	15.39	16.92	19.04	20.38	24.46	28.23
90	7.39	9.60	11.69	13.81	15.92	17.59	19.79	21.30	25.56	29.80
100	7.50	9.81	11.97	14.18	16.34	18.13	20.40	22.04	26.45	31.06
110	7.59	9.99	12.20	14.48	16.68	18.57	20.89	22.65	27.18	32.09
120	7.67	10.13	12.39	14.73	16.97	18.94	21.31	23.16	27.79	32.95
130	7.73	10.26	12.55	14.94	17.21	19.25	21.66	23.58	28.30	33.68
140	7.79	10.36	12.69	15.12	17.42	19.51	21.96	23.95	28.74	34.30
150	7.83	10.46	12.81	15.28	17.60	19.75	22.22	24.27	29.12	34.84
160	7.88	10.54	12.91	15.42	17.75	19.95	22.44	24.55	29.46	35.32
170	7.91	10.61	13.01	15.54	17.89	20.13	22.65	24.79	29.75	35.7
180	7.94	10.67	13.10	15.67	18.02	20.29	22.82	25.00	30.02	36.14
190	7.97	10.71	13.17	15.75	18.13	20.43	23.00	25.20	30.26	36.50
200	8.00	10.75	13.23	15.83	18.23	20.56	23.13	25.39	30.46	36.75
210	8.02	10.83	13.29	15.91	18.32	20.67	23.26	25.55	30.65	37.02
220	8.16	10.87	13.35	15.90	18.40	20.78	23.38	25.69	30.83	37.27
230	8.51	11.18	13.85	16.10	18.47	20.87	23.49	25.82	30.99	37.50
240	8.83	11.65	14.43	16.81	19.29	21.21	23.86	25.94	31.13	37.70
250	9.01	11.88	14.75	17.59	20.39	23.15	25.87	28.55	33.81	41.12
260	9.41	12.48	15.45	18.10	20.77	22.97	25.84	28.04	33.64	40.18
270	9.66	12.86	15.91	18.67	21.43	23.76	26.73	29.05	34.86	41.72
280	9.91	13.21	16.34	19.21	22.06	24.50	27.57	30.00	36.00	43.16
290	10.38	13.54	16.74	19.71	22.64	25.19	28.34	30.88	37.04	44.51
300	10.89	13.85	17.12	20.19	23.18	25.84	29.07	31.71	38.06	45.78

Table 8.4. Shear values load class 3–30 tons (spans 4–300 ft) wheeled vehicles

Span	MLC3	MLC4	MLC5	MLC8	MLC9	MLC12	MLC16	MLC20	MLC24	MLC30
4	1.40	2.50	2.88	5.50	6.10	8.00	10.00	11.00	12.00	13.50
6	1.40	2.50	2.88	5.50	6.10	8.00	10.00	11.33	13.33	14.67
8	1.48	2.63	2.88	5.50	6.10	8.00	10.00	12.75	15.00	16.50
10	1.64	2.80	2.99	5.50	6.10	8.00	10.40	13.60	16.00	17.60
12	1.74	2.92	3.20	5.50	6.10	8.33	10.83	14.17	16.67	18.33
14	1.82	3.14	3.35	5.50	6.14	8.57	11.14	14.57	17.14	18.86
16	1.66	3.31	3.46	5.63	6.49	9.13	11.75	15.38	18.30	20.00
18	1.92	3.44	3.54	6.00	6.75	9.56	12.22	16.00	18.89	20.89
20	1.96	3.55	3.61	6.30	6.97	9.90	12.60	16.50	19.50	21.60
25	2.02	3.74	3.74	6.84	7.35	10.52	13.28	17.40	20.60	22.88
30	2.06	3.87	3.82	7.20	7.61	10.93	13.73	18.00	21.33	23.73
35	2.09	3.96	3.88	7.46	7.79	11.23	14.06	18.43	21.86	24.34
40	2.12	4.03	3.92	7.65	7.93	11.45	14.30	18.75	22.25	24.80
45	2.13	4.08	3.96	7.80	8.03	11.62	14.49	19.00	22.56	25.16
50	2.15	4.12	3.98	7.92	8.12	11.76	14.64	19.20	22.80	25.60
55	2.16	4.15	4.00	8.02	8.19	11.87	14.76	19.36	23.00	26.36
60	2.17	4.18	4.03	8.10	8.25	12.13	14.87	19.50	23.17	27.00
70	2.18	4.23	4.05	8.23	8.34	12.54	15.34	19.97	23.46	28.00
80	2.19	4.26	4.08	8.33	8.41	12.85	15.74	20.48	24.03	28.75
90	2.20	4.29	4.09	8.40	8.46	13.09	16.04	20.87	24.47	29.33
100	2.21	4.31	4.10	8.46	8.50	13.28	16.29	21.18	24.82	29.80
110	2.25	4.33	4.14	8.51	8.54	13.44	16.50	21.44	25.11	30.18
120	2.41	4.52	4.41	8.75	8.88	13.57	16.65	21.65	25.35	30.50
130	2.57	4.83	4.72	9.28	9.40	13.77	16.89	21.95	25.71	30.95
140	2.72	5.13	4.99	9.90	10.00	14.21	17.41	22.63	26.51	31.91
150	2.84	5.39	5.22	10.44	10.52	15.13	18.55	24.12	28.28	33.92
160	2.94	5.61	5.42	10.91	10.97	16.04	19.67	25.58	29.98	35.98
170	3.04	5.81	5.56	11.33	11.37	16.86	20.69	26.89	31.51	37.86
180	3.12	5.99	5.76	11.70	11.73	17.59	21.59	28.07	32.87	39.53
190	3.20	6.15	5.90	12.03	12.05	18.24	22.41	29.12	33.67	41.03
200	3.26	6.29	6.03	12.33	12.33	18.83	23.14	30.06	35.18	42.38
210	3.33	6.42	6.15	12.60	12.59	19.36	23.80	30.91	36.17	43.60
220	3.42	6.54	6.27	12.84	12.83	19.85	24.40	31.69	37.07	44.71
230	3.56	6.70	6.51	13.10	13.11	20.29	24.94	32.40	37.90	45.72
240	3.69	6.96	6.76	13.53	13.56	20.69	25.45	33.05	38.65	46.65
250	3.82	7.25	7.00	14.04	14.07	21.06	25.91	33.65	39.34	47.50
260	3.93	7.47	7.22	14.54	14.55	21.50	26.43	34.32	40.14	48.49
270	4.04	7.69	7.42	15.00	15.00	22.15	27.22	35.36	41.36	49.91
280	4.14	7.90	7.61	15.43	15.42	22.91	28.16	36.58	42.79	51.60
290	4.23	8.09	7.79	15.83	15.80	23.67	29.10	37.50	44.21	53.34
300	4.32	8.27	7.95	16.20	16.17	24.38	29.98	38.94	45.54	54.96

Table 8.5. Shear values load class 30–150 tons (spans 4–300 ft) wheeled vehicles

Span	MLC30	MLC40	MLC50	MLC60	MLC70	MLC80	MLC90	MLC100	MLC120	MLC150
4	13.50	17.00	20.00	23.00	25.50	28.00	30.00	32.00	36.00	42.00
6	14.67	17.33	20.00	23.00	25.50	28.00	31.50	32.00	36.00	42.00
8	16.50	19.50	22.50	24.75	28.88	33.00	37.13	37.50	45.00	47.25
10	17.60	20.80	24.00	27.00	31.50	36.00	40.50	42.00	50.40	54.60
12	18.33	21.67	25.00	28.50	33.25	38.00	42.75	45.00	54.00	59.50
14	18.86	22.29	25.71	29.57	34.50	39.43	44.36	47.14	56.57	63.00
16	20.00	22.75	26.25	30.38	35.44	40.50	45.56	48.75	58.50	65.63
18	20.89	23.89	27.56	31.44	36.75	42.00	47.25	50.00	60.00	67.67
20	21.60	24.80	28.60	32.90	38.88	43.90	49.98	52.40	63.10	70.00
25	22.88	26.72	31.60	35.52	41.16	47.04	52.92	57.00	68.40	77.52
30	23.73	28.93	34.67	39.93	5.97	49.20	55.35	60.02	72.02	82.98
35	24.34	30.51	36.86	43.09	49.40	53.26	59.91	64.57	77.49	85.66
40	24.80	31.70	38.50	45.45	51.98	56.60	63.68	69.00	82.80	89.45
45	25.16	32.62	40.31	47.29	53.98	59.20	66.60	72.44	86.93	95.76
50	25.60	33.36	42.08	48.76	55.58	61.28	68.94	75.20	90.24	101.20
55	26.36	34.42	43.53	49.96	56.89	62.98	70.85	77.45	92.94	105.40
60	27.00	35.47	44.73	51.43	58.22	64.40	72.45	79.33	95.20	109.00
70	28.00	37.11	46.63	54.09	61.40	66.63	74.96	82.29	98.74	114.70
80	28.75	38.35	48.05	56.08	63.79	69.70	78.41	84.69	101.60	121.60
90	29.33	39.31	49.16	57.62	65.64	72.18	81.20	88.06	105.70	127.00
100	29.80	40.08	50.04	58.86	67.13	74.16	83.43	90.75	108.90	131.30
110	30.18	40.71	50.76	59.87	68.35	75.78	85.25	92.95	111.50	134.80
120	30.50	41.23	51.37	60.71	69.36	77.13	86.77	94.79	113.80	137.70
130	30.95	41.68	51.88	61.43	70.22	78.30	86.06	96.35	115.60	140.20
140	31.91	42.86	53.46	62.41	71.35	79.26	89.16	97.68	117.20	142.30
150	33.92	44.24	55.29	63.57	73.88	81.71	91.92	100.00	120.00	144.80
160	35.98	46.75	58.40	67.18	76.65	84.35	94.89	103.50	124.20	149.80
170	37.86	49.36	61.60	70.99	80.99	87.95	98.95	106.90	128.20	154.80
180	39.53	51.84	64.62	74.74	85.31	92.62	104.20	112.20	134.60	160.30
190	41.03	54.06	67.33	78.17	89.31	7.43	109.60	117.90	141.50	168.20
200	42.38	56.06	69.76	81.26	92.89	101.80	14.50	123.50	148.20	176.30
210	43.60	57.87	71.96	84.06	96.13	105.70	118.90	128.60	154.30	184.10
220	44.71	59.51	73.96	86.60	99.08	109.20	122.90	133.20	159.80	191.20
230	45.72	61.01	75.79	88.92	101.80	112.50	126.60	137.40	164.90	197.70
240	46.65	63.28	77.47	91.05	104.20	115.50	129.90	141.30	169.50	203.60
250	47.50	63.65	79.00	93.01	106.50	118.20	133.00	144.80	173.00	209.10
260	48.49	64.82	80.43	94.82	108.60	120.70	135.80	148.10	177.70	214.10
270	49.91	66.21	82.19	96.49	110.40	122.10	138.50	152.10	181.00	218.80
280	51.60	67.70	84.11	98.60	113.00	125.30	140.90	153.90	184.70	222.10
290	53.34	69.81	86.73	100.92	115.40	128.10	144.10	156.80	188.20	227.10
300	54.96	72.04	89.48	103.57	118.90	131.00	147.40	160.60	192.70	231.80

Table 8.6. UBM values load class 3–30 tons (spans 4–300 ft) tracked vehicles

Span	MLC 3	MLC 4	MLC 5	MLC 8	MLC 9	MLC 12	MLC 16	MLC 20	MLC 24	MLC 30
4	0.35	0.33	0.72	0.61	1.53	0.68	0.89	1.11	1.33	1.36
6	0.35	0.50	0.72	0.92	1.53	1.00	1.33	1.67	2.00	2.04
8	0.35	0.62	0.72	1.19	1.53	1.33	1.78	2.22	2.67	2.73
10	0.35	0.70	0.72	1.35	1.53	1.65	2.20	2.75	3.30	3.41
12	0.35	0.75	0.72	1.46	1.53	1.87	2.50	3.12	3.75	4.06
14	0.36	0.79	0.72	1.54	1.53	2.04	2.71	3.39	4.07	4.55
16	0.39	0.81	0.72	1.59	1.53	2.16	2.87	3.59	4.31	4.92
18	0.41	0.83	0.74	1.63	1.53	2.24	3.00	3.71	4.32	5.18
20	0.42	0.85	0.77	1.67	1.53	2.32	3.10	3.87	4.65	5.44
25	0.45	0.88	0.82	1.74	1.53	2.46	3.28	4.10	4.92	5.85
30	0.47	0.90	0.86	1.78	1.63	2.55	3.40	4.25	5.10	6.12
35	0.48	0.91	0.89	1.81	1.70	2.61	3.49	4.36	5.23	6.32
40	0.49	0.92	0.91	1.84	1.77	2.66	3.55	4.44	5.32	6.47
45	0.50	0.93	0.92	1.86	1.82	2.70	3.60	4.50	5.40	6.58
50	0.51	0.94	0.94	1.67	1.85	2.73	3.64	4.55	5.46	6.67
55	0.51	0.94	0.95	1.88	1.89	2.75	3.67	4.59	5.51	6.75
60	0.52	0.95	0.96	1.89	1.91	2.77	3.70	4.62	5.55	6.81
70	0.52	0.96	0.97	1.91	1.96	2.81	3.74	4.68	5.61	6.91
80	0.53	0.96	0.98	1.92	1.99	2.83	3.77	4.72	5.66	6.98
90	0.53	0.97	0.99	1.93	2.01	2.85	3.80	4.75	5.70	7.04
100	0.54	0.97	1.00	1.94	2.03	2.87	3.82	4.77	5.73	7.08
110	0.54	0.97	1.00	1.94	2.05	2.88	3.84	4.79	5.75	7.12
120	0.54	0.97	1.00	1.95	2.06	2.89	3.85	4.81	5.77	7.16
130	0.54	0.98	1.01	1.95	2.08	2.90	3.86	4.83	5.79	7.18
140	0.55	0.98	1.01	1.95	2.09	2.90	3.87	4.84	5.81	7.20
150	0.55	0.98	1.02	1.96	2.10	2.91	3.88	4.85	5.82	7.22
160	0.55	0.98	1.02	1.96	2.10	2.92	3.89	4.86	5.83	7.24
170	0.55	0.98	1.02	1.96	2.11	2.92	3.89	4.87	5.84	7.26
180	0.55	0.98	1.02	1.96	2.12	2.92	3.90	4.87	5.85	7.27
190	0.55	1.00	1.06	2.04	2.12	2.99	3.99	4.99	5.99	7.34
200	0.58	1.07	1.10	2.13	2.22	3.12	4.16	5.20	6.24	7.67
210	0.60	1.11	1.14	2.20	2.31	3.24	4.32	5.40	6.48	7.97
220	0.64	1.14	1.18	2.28	2.40	3.35	4.47	5.58	6.70	8.25
230	0.66	1.17	1.22	2.34	2.48	3.45	4.60	5.75	6.90	8.50
240	0.68	1.22	1.25	2.42	2.55	3.55	4.73	5.91	7.09	8.74
250	0.72	1.25	1.30	2.57	2.61	3.71	4.95	6.19	7.43	9.00
260	0.76	1.36	1.37	2.70	2.70	3.92	5.22	6.53	7.83	9.53
270	0.79	1.42	1.44	2.82	2.85	4.11	5.47	6.84	8.21	0.01
280	0.82	1.47	1.50	2.93	2.99	4.28	5.71	7.13	8.56	10.46
290	0.85	1.53	1.56	3.04	3.11	4.44	5.92	7.40	8.89	10.87
300	0.88	1.55	1.61	3.14	3.23	4.50	6.13	7.60	9.10	11.20

Table 8.7. UBM values load class 30–150 tons (spans 4–300 ft) tracked vehicles

Span	MLC30	MLC40	MLC50	MLC60	MLC70	MLC80	MLC90	MLC100	MLC120	MLC150
4	1.36	1.67	1.92	2.14	2.33	2.50	2.65	2.78	3.00	3.12
6	2.04	2.50	2.88	3.21	3.50	3.75	3.97	4.17	4.50	4.69
8	2.73	3.33	3.85	4.29	4.67	5.00	5.29	5.56	6.00	6.25
10	3.41	4.17	4.81	5.36	5.83	6.25	6.62	6.94	7.50	7.81
12	4.06	5.00	5.77	6.43	7.00	7.50	7.94	8.33	9.00	9.37
14	4.55	5.71	6.70	7.50	8.17	8.75	9.26	9.72	10.50	10.94
16	4.92	6.25	7.42	8.44	9.30	10.00	10.59	11.11	12.00	12.50
18	5.18	6.62	7.93	9.16	10.21	11.11	11.87	12.50	13.50	14.06
20	5.44	7.00	8.44	9.75	10.94	12.00	12.94	13.75	15.00	16.62
25	5.85	7.60	9.25	10.80	12.25	13.60	14.85	16.00	18.00	19.50
30	6.12	8.00	9.79	11.50	13.12	14.67	16.12	17.50	20.00	22.50
35	6.32	8.29	10.18	12.00	13.75	15.43	17.04	18.57	21.43	24.64
40	6.47	8.50	10.47	12.37	14.22	16.00	17.72	19.37	22.50	26.25
45	6.58	8.67	10.69	12.67	14.58	16.44	18.25	20.00	23.33	27.50
50	6.67	8.80	10.81	12.92	14.87	16.87	18.67	20.50	24.00	28.50
55	6.75	8.91	11.02	13.09	15.11	17.09	19.02	20.91	24.54	29.32
60	6.81	9.00	11.15	13.25	15.31	17.33	19.31	21.25	25.00	30.00
70	6.91	9.14	11.34	13.50	15.62	17.71	19.77	21.79	25.71	31.07
80	6.98	9.25	11.48	13.69	15.86	18.00	20.11	22.19	26.25	31.87
90	7.04	9.33	11.60	13.83	16.04	18.22	20.37	22.50	26.67	32.50
100	7.08	9.39	11.68	13.93	16.18	18.37	20.56	22.74	27.00	32.96
110	7.12	9.45	11.76	14.04	16.31	18.54	20.76	22.95	27.27	33.41
120	7.16	9.50	11.82	14.12	16.41	18.67	20.91	23.12	27.50	33.75
130	7.18	9.54	11.87	14.19	16.49	18.77	21.03	23.27	27.69	34.04
140	7.20	9.57	11.92	14.25	16.56	18.86	21.13	23.39	27.86	34.29
150	7.22	9.60	11.96	14.30	16.62	18.93	21.22	23.50	28.00	34.50
160	7.24	9.62	11.99	14.34	16.68	19.00	21.30	23.59	28.12	34.69
170	7.26	9.65	12.02	14.38	16.73	19.06	21.37	23.68	28.23	34.85
180	7.27	9.67	12.05	14.42	16.77	19.10	21.44	23.75	28.30	35.00
190	7.34	9.69	12.07	14.45	16.81	19.16	21.49	23.82	28.42	35.13
200	7.67	10.13	12.55	14.92	17.24	19.52	21.75	23.93	28.50	35.25
210	7.97	10.54	13.06	15.54	17.97	20.36	22.70	25.00	29.47	35.51
220	8.25	10.91	13.53	16.11	18.64	21.14	23.59	25.99	30.68	37.08
230	8.50	11.26	13.97	16.64	19.27	21.86	24.40	26.91	31.80	38.52
240	8.74	11.58	14.38	17.13	19.85	22.53	25.16	27.76	32.84	39.87
250	9.00	11.88	14.75	17.59	20.39	23.15	25.87	28.55	33.81	41.12
260	9.53	12.54	15.46	18.29	21.03	23.73	26.53	29.29	34.71	42.29
270	10.01	13.18	16.27	19.28	22.20	25.04	27.79	30.46	35.56	43.38
280	10.46	13.79	17.03	20.20	23.28	26.29	29.21	32.05	37.50	44.46
290	10.87	14.34	17.74	21.05	24.29	27.45	30.53	33.53	39.31	46.81
300	11.20	14.80	18.40	21.85	25.20	28.50	31.70	34.90	41.00	49.00

Table 8.8. Shear values load class 3–30 in tons (spans 4–300 ft) tracked vehicles

Span	MLC4	MLC5	MLC8	MLC9	MLC12	MLC16	MLC20	MLC24	MLC30
4	1.33	1.48	2.46	2.07	2.67	3.56	4.44	5.33	5.46
6	2.00	2.23	3.69	3.11	4.00	5.33	6.67	8.00	8.18
8	2.50	2.78	4.75	4.14	5.33	7.11	8.89	10.67	10.91
10	2.80	3.12	5.40	4.92	6.60	8.88	11.00	13.20	13.64
12	3.00	3.34	5.83	5.44	7.50	10.00	12.50	15.00	16.25
14	3.14	3.50	6.14	5.81	8.14	10.86	13.57	16.28	18.22
16	3.25	3.62	6.38	6.09	8.62	11.50	14.38	17.25	19.69
18	3.33	3.71	6.56	6.30	9.00	12.00	15.00	18.00	20.83
20	3.40	3.79	6.70	6.48	9.30	12.40	15.50	18.60	21.75
25	3.52	3.92	6.96	6.79	9.84	13.12	16.40	19.68	23.40
30	3.60	4.01	7.13	6.99	10.20	13.60	17.00	20.40	24.50
35	3.66	4.08	7.26	7.14	10.46	13.94	17.43	20.92	15.28
40	3.70	4.12	7.35	7.25	10.65	14.20	17.75	21.30	25.88
45	3.73	4.16	7.42	7.34	10.80	14.40	18.00	21.60	26.33
50	3.76	4.19	7.48	7.41	10.92	14.56	18.20	21.84	26.70
55	3.78	4.21	7.53	7.47	11.02	14.69	18.36	22.04	27.00
60	3.80	4.24	7.57	7.51	11.10	14.80	18.50	22.20	27.25
70	3.83	4.27	7.63	7.59	11.23	14.97	18.72	22.46	27.64
80	3.85	4.29	7.68	7.64	11.32	15.10	18.88	22.65	27.94
90	3.87	4.31	7.71	7.69	11.40	15.20	19.00	22.80	28.17
100	3.90	4.32	7.74	7.72	11.66	15.28	19.10	22.92	28.35
110	3.94	4.32	7.83	7.72	11.52	15.35	19.19	23.03	28.50
120	4.27	4.76	8.47	8.33	12.20	16.27	20.33	24.40	29.55
130	4.55	5.08	9.05	8.93	13.10	17.48	21.85	26.22	31.85
140	4.80	5.35	9.54	9.44	13.89	18.51	23.14	27.77	33.86
150	5.01	5.59	9.97	9.88	14.56	19.41	24.27	29.12	35.60
160	5.20	5.80	10.35	10.26	15.15	20.20	25.25	30.30	37.13
170	5.36	5.98	10.68	10.61	15.67	20.89	26.12	31.34	38.47
180	5.50	6.14	10.91	10.91	16.12	21.42	26.96	32.00	39.00
190	5.64	6.29	11.24	11.18	16.55	22.06	27.58	33.09	40.74
200	5.76	6.42	11.48	11.42	16.92	22.56	28.20	33.84	41.70
210	5.87	6.54	11.70	11.65	17.26	23.01	28.76	34.51	42.57
220	6.05	6.75	12.03	11.89	17.58	23.43	29.29	35.15	43.36
230	6.31	7.04	12.55	12.40	18.23	24.31	30.39	36.47	44.47
240	6.55	7.30	13.02	12.89	18.97	25.30	31.62	37.95	46.31
250	6.77	7.54	13.46	13.34	19.66	26.21	32.76	39.31	48.06
260	6.97	7.77	13.87	13.75	20.28	27.08	33.81	40.57	49.67
270	7.16	7.98	14.24	14.13	20.87	27.82	34.78	41.73	51.17
280	7.33	8.17	14.59	14.49	21.41	28.54	35.68	42.81	52.55
290	7.49	8.35	14.92	14.82	21.91	29.21	36.52	43.82	53.84
300	7.64	8.52	15.22	15.13	22.38	29.84	37.30	44.76	55.06

Table 8.9. Shear values load class 30–150 in tons (spans 4–300 ft) tracked vehicles

Span	MLC30	MLC40	MLC50	MLC60	MLC70	MLC80	MLC90	MLC100	MLC120	MLC150
4	5.46	6.67	7.69	8.57	9.33	10.00	10.59	11.11	12.00	12.50
6	8.18	10.00	11.54	12.86	14.00	15.00	15.88	16.67	18.00	18.75
8	10.91	13.33	15.38	17.14	18.67	20.00	21.18	23.22	24.00	25.00
10	13.64	16.67	19.23	21.43	23.33	25.00	26.47	27.78	30.00	31.25
12	16.25	20.00	23.06	25.72	28.00	30.00	31.06	33.33	36.00	37.50
14	18.22	22.86	26.78	30.00	32.67	35.00	37.06	38.89	42.00	43.75
16	19.69	25.00	29.69	33.75	37.19	40.00	42.35	44.44	48.00	50.00
18	20.83	26.67	31.94	36.67	40.83	44.44	47.50	50.00	54.00	56.25
20	21.75	28.00	33.75	39.00	43.75	48.00	51.75	55.00	60.00	62.50
25	23.40	30.40	37.00	43.20	49.00	54.40	59.40	64.00	72.00	78.00
30	24.50	32.00	39.17	46.00	52.50	58.67	64.50	70.00	80.00	90.00
35	25.28	33.14	40.72	48.00	55.00	61.72	68.14	74.28	85.71	98.57
40	25.88	34.00	41.88	49.50	56.88	64.00	70.88	77.50	90.00	105.00
45	26.33	34.67	42.78	50.67	58.33	65.78	73.00	80.00	93.33	110.00
50	26.70	35.20	43.50	51.60	59.50	67.20	74.70	82.00	96.00	114.00
55	27.00	35.64	44.09	52.36	60.46	68.36	76.09	83.64	98.18	117.30
60	27.25	36.00	44.58	53.00	61.25	69.33	77.25	85.00	100.00	120.00
70	27.64	36.57	45.36	54.00	62.50	70.86	79.02	87.14	102.90	124.30
80	27.94	37.00	45.94	54.75	63.44	72.00	80.44	87.75	105.00	127.50
90	28.17	37.33	46.39	55.33	64.17	72.89	81.50	90.00	106.70	130.00
100	28.35	37.60	46.75	55.80	64.75	73.60	82.35	91.00	108.00	132.00
110	28.50	37.82	47.04	56.18	65.23	74.18	83.04	91.82	109.10	133.60
120	29.55	38.89	48.08	57.14	66.11	75.00	83.82	92.59	110.00	135.00
130	31.85	41.85	51.54	60.93	70.00	78.85	87.56	96.15	113.10	137.00
140	33.86	44.57	55.00	65.14	75.00	84.57	93.86	102.90	120.00	142.90
150	35.60	46.93	58.00	68.80	79.33	89.60	99.60	109.30	128.00	152.00
160	37.13	49.00	60.63	72.00	83.13	93.89	104.60	115.00	135.00	161.30
170	38.47	50.82	62.94	74.82	86.47	97.77	109.10	120.00	141.20	169.40
180	39.00	52.00	65.00	77.40	89.00	101.00	113.00	124.00	146.00	176.00
190	40.74	53.89	66.84	79.58	92.10	104.30	116.50	128.40	151.60	183.20
200	41.70	55.20	68.50	81.60	94.50	107.10	119.70	132.00	156.00	189.00
210	42.57	56.38	70.00	83.43	96.67	109.60	122.60	135.20	160.00	194.30
220	43.36	57.45	71.36	85.09	98.64	112.00	125.20	138.20	163.60	199.10
230	44.47	58.70	72.74	86.65	100.40	114.10	127.60	140.90	167.00	203.50
240	46.31	61.00	75.31	89.29	103.10	116.70	130.10	143.50	170.00	207.50
250	48.06	63.36	78.30	92.88	107.10	121.00	134.50	147.70	174.00	211.30
260	49.67	65.54	81.04	96.23	111.10	125.50	139.70	153.50	180.00	216.30
270	51.17	67.56	83.61	99.33	114.70	129.80	144.50	158.90	186.70	223.40
280	52.55	69.43	85.98	102.20	118.10	133.70	149.00	163.90	192.90	231.40
290	53.84	71.17	88.19	104.90	121.30	137.40	153.20	168.60	198.40	239.00
300	55.06	72.80	90.25	107.40	124.30	140.80	157.10	173.00	204.00	246.00

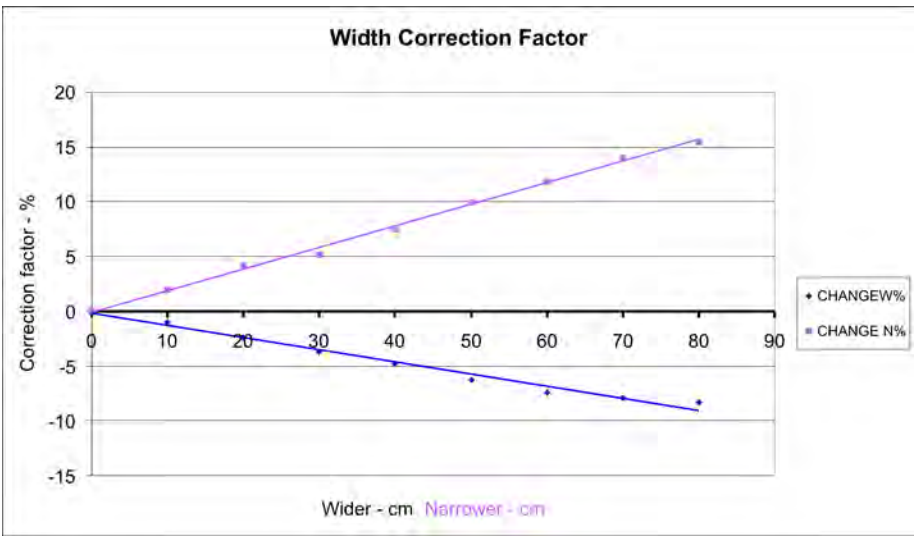
B7 CLASSIFYING VEHICLES

Research & Development Establishment (Engrs), Dighi, Pune is the authority for classifying all vehicles used in the services. If in an emergency it has to be done by Engineers, early confirmation should be sought from the R&DE (Engrs), the information required to be provided being shown in the proforma in Fig. 8.1.

Solo vehicles, the components of combination vehicles (for example, prime mover and associated trailer or gun) and other trailers will be classified independently in the fully laden state.

Table 8.10. Vehicle width adjustment factor

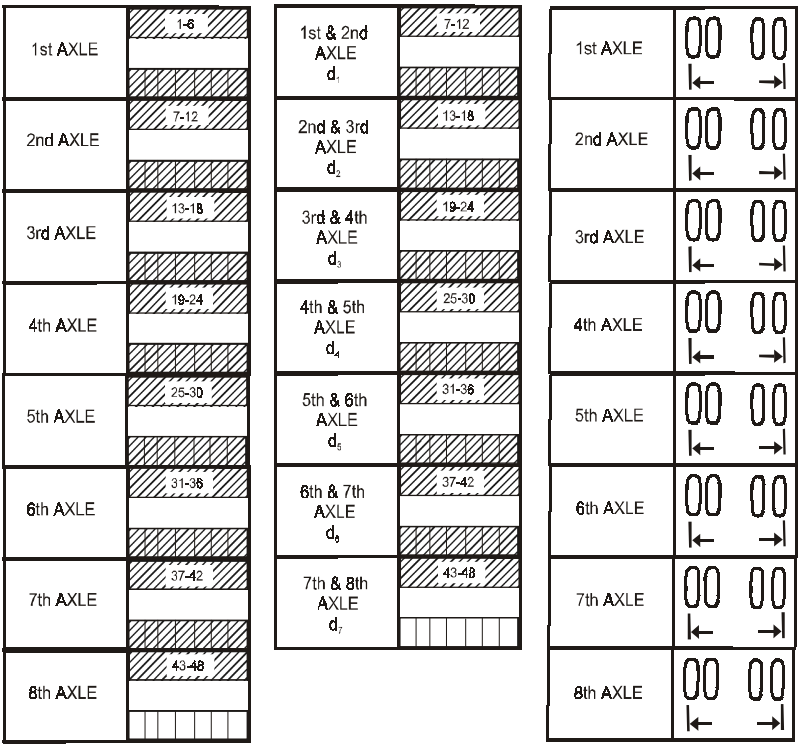
WIDER (cm)	0.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00
CHANGE (W%)	0.00	-1.00	-2.40	-3.70	-4.80	-6.30	-7.40	-7.90	-8.30
CHANGE (N%)	0.00	2.00	4.18	5.20	7.50	9.96	11.88	14.00	15.50



Tank transporters and other combinations normally associated together will be classified as a complete laden train. In addition, they may be classified as complete unladen train. Vehicles or combination of vehicles, having a gross weight of 1.5 t or less need not be classified.

1. WHEELED VEHICLE

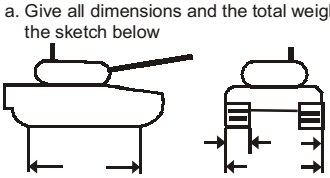
a. Full Service Designation of the Vehicle
b. Number of Axes of the Vehicle Train
c. Axle Load in metric tonnes
d. Distance between successive axles in metres
e. Distance between tyres in metres/cms



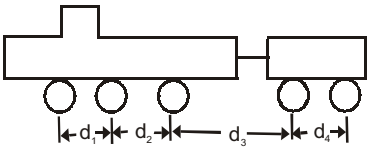
Hatched portion is meant for the use of R&DE (E) only

TRACKED VEHICLE

a. Give all dimensions and the total weight in the sketch below



Position of Axles and Distances with respect of direction of Travel



INSTRUCTIONS

1. For laden and unladen conditions use separate formats. For each case send two copies. One copy will be returned to you after filling the vehicle classification number.
2. Loads must be given in Kgs or tonnes.
3. Laden = Vehicle in travelling condition fully kitted and equipped plus crew full fuel tank and maximum permissible payload (if any)
4. Unladen = Laden less maximum pay load (if any). State if not applicable.
5. Cranes are classified with no load on hook
6. In case of tractor trailer combinations, give the distance between rearmost axle of towing vehicle & frontmost axle of towed vehicle.
7. In case of single axle semi-trailers like guns, the axle weights of the combination be given instead of axle weights of individual tractor trailer.
8. Wherever possible, additional information may be given with the help of a photograph or a diagrammatic sketch.

Figure 8.1. Data sheet for classification of new vehicle.

Baggage or other pole type trailers with rated capacity of 1.5 t or less will normally be combined with their towing vehicle for classification purposes.

Cranes, recovery vehicles, and forklift trucks will be classified with designed load on their hooks or on forks.

Laden vehicles will be assumed to be carrying the maximum load specified for them and no further overloading is assumed.

All vehicles will be designated the classification number, which will be the nearest whole number to the classification number so worked out by the described procedure.

A simple guide for use by all arms in dealing with a non-standard train of two vehicles is to use the sum of the load class numbers of each vehicle. It is possible however, to apply the following rules when considering nonstandard trains - "when one vehicle is towing another not normally associated with it, the load class number of the train can be taken as two thirds of the class number of the lower class vehicle plus the class number of the other vehicle". The classification number of a vehicle is usually governed by the UBM or shear it can impose and more rarely by its maximum axle of tyre load.

B8 PROCEDURE

To classify a specific vehicle or combination, it is necessary to calculate the unit bending moments and shear forces which it produces on various spans up to 100 m. The values so obtained are plotted over the appropriate classification curves of the hypothetical vehicles.

The following assumptions are made when calculating values for plotting :

(a) No allowance is made for impact effects

(b) Vehicles: wheeled or tracked are in convoys with 30.48 m spacing between ground contact points of vehicle.

The vehicle class is determined by interpolation between the curves at the point which gives the maximum classification number.

Both wheeled and tracked vehicles up to class 30 will be classified by interpolation between the curves shown at Figs. 8.5, 8.9, and 8.10.

Wheeled vehicles or tracked vehicles over class 30 will be classified by interpolation between the appropriate curves shown at Figs. 8.2, 8.3, 8.4, 8.8, and 8.11.

The interpolated classification number is then adjusted if necessary for the width effect. A comparison is made between ground contact width of the vehicle and of the hypothetical vehicles belonging to the nearest higher class. This determines the width deviation and reference to Table 8.10 will show how much the interpolated classification number must be increased or decreased. The final classification number is arrived at accordingly.

Check maximum tyre load of vehicle against hypothetical tyre loads in column 12 of Table 8.1.

B9 NATO AGREEMENT STANAG – 2021

Although the earlier paragraphs explain the underlying principles behind the standard military load classification system, it is written with the Indian context in mind. The need to have a common standard for all the countries need not be over emphasized; rather it is natural to adopt a common standard to enable one to compare the bridges especially the equipment bridges produced by different countries by one common standard. The suggested adoption for the Indian system does not in any way violate this basic principle behind the NATO standard. The NATO standard, covered by the standard agreement Stanag 2021 a common reference material. Admittedly, there is a confusion created for the Indian system due to the fact that the Indian edition of Military Engineering, Vol III, 1968, carries altogether different load class numbers and UBM/shear curves without in any way even mentioning that this system departs from the British system published by the War Office, London. Essentially, the British system provides the base for the NATO Agreement, which adopts the British system by converting it to the metric system. The reference to the NATO system is considered essential if we want to carry out a comparative study of the bridges produced by different countries by a common standard. Even the Russian system is imperfect as it oversimplifies the problem by classifying the bridges by the gross vehicle weight that it is supposed to carry.

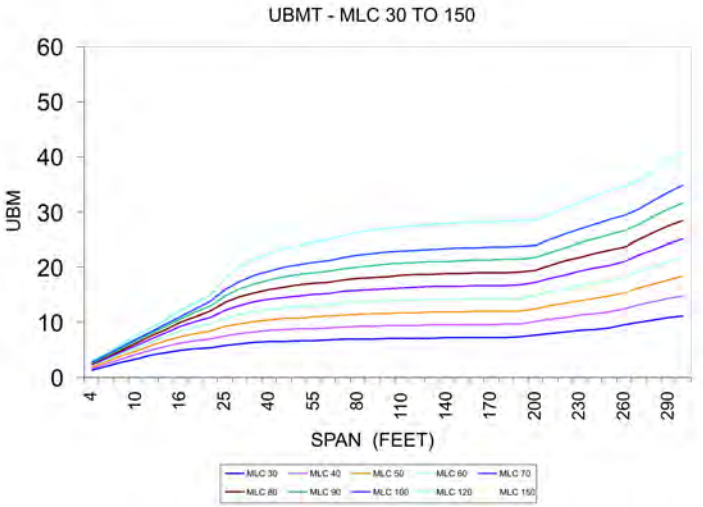


Figure 8.2. UBMT – MLC 30 to 150.

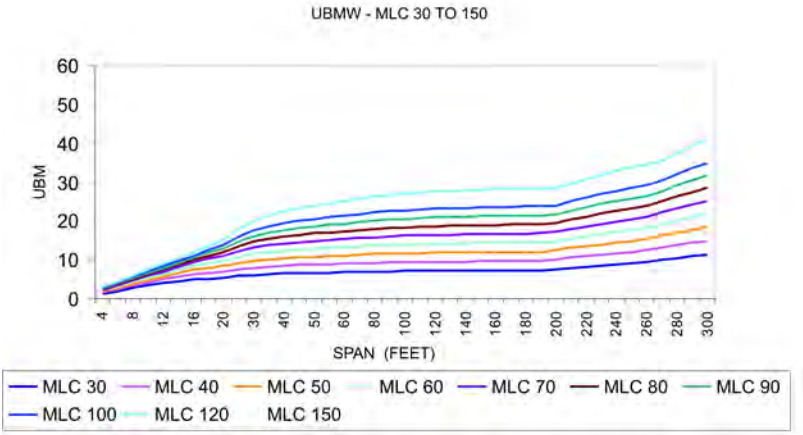


Figure 8.3. UBMW – MLC 30 to 150.

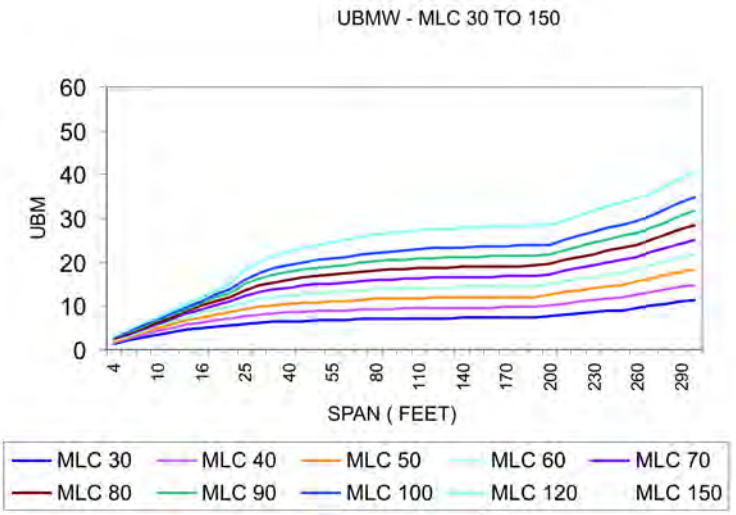


Figure 8.4. UBMW – MLC 30 to 150.

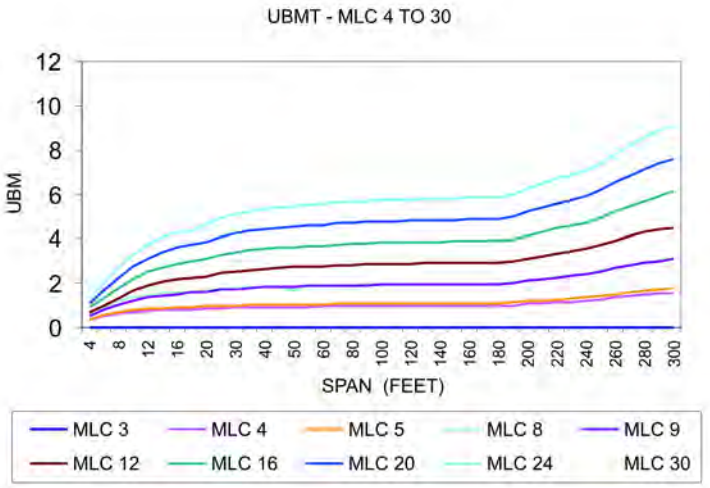


Figure 8.5. UBMT – MLC 4 to 30.

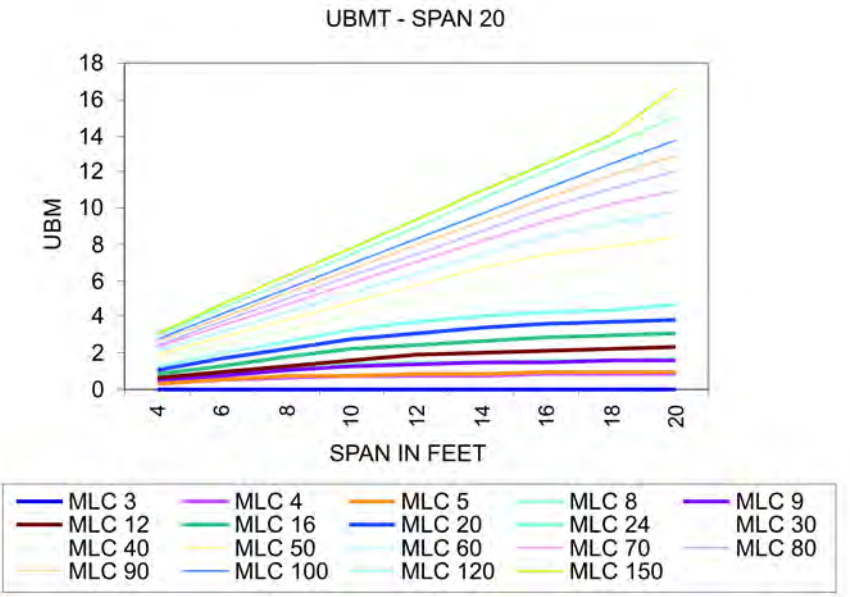


Figure 8.6. UBMT – Span 20.

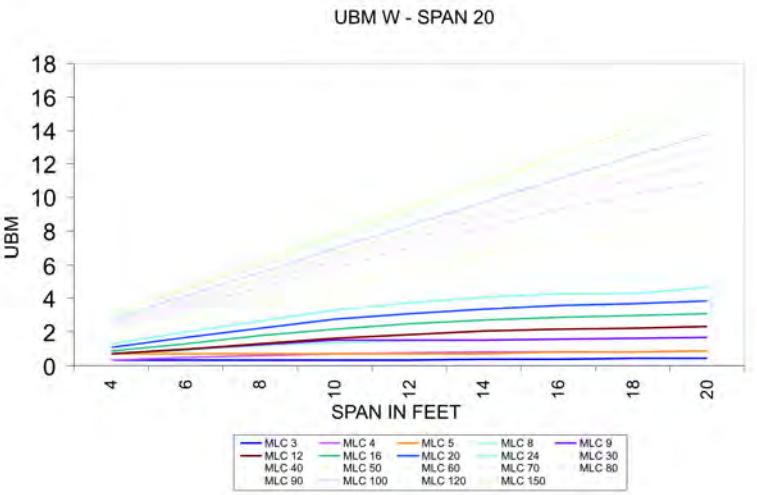


Figure 8.7. UBMW – Span 20.

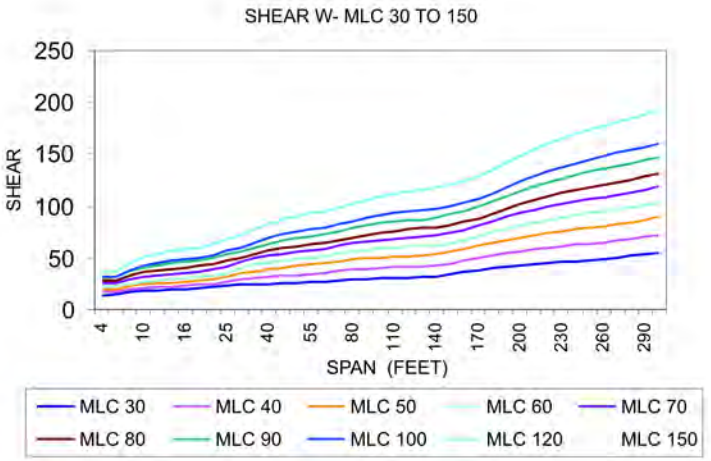


Figure 8.8. Shear W – MLC 30 to 150.

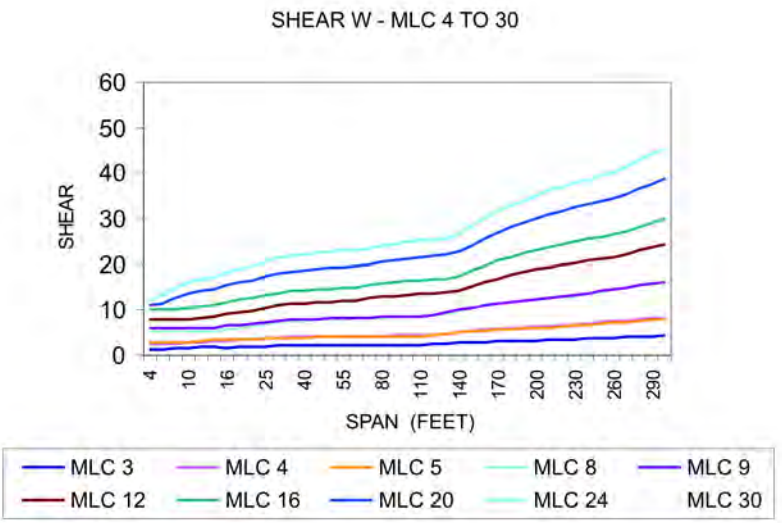


Figure 8.9. Shear W – MLC 4 to 30.

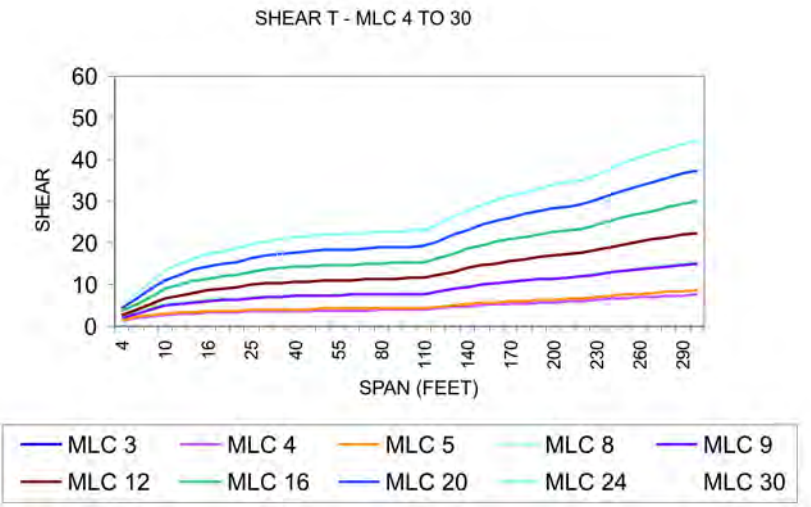


Figure 8.10. Shear T – MLC 4 to 30.

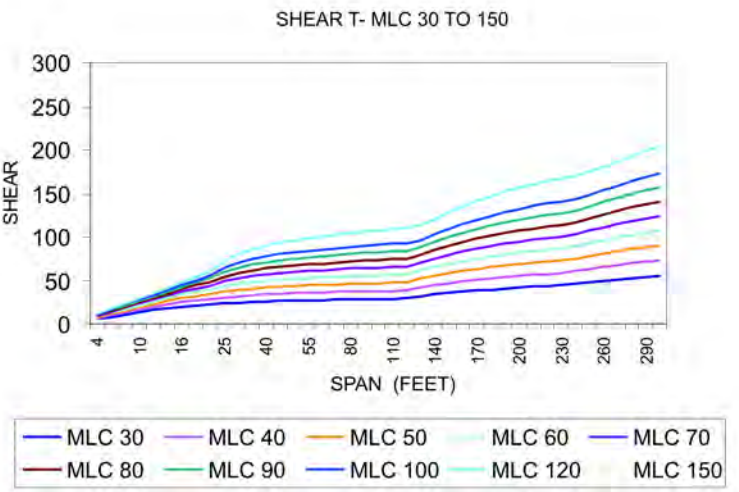


Figure 8.11. Shear T – MLC 30 to 150.

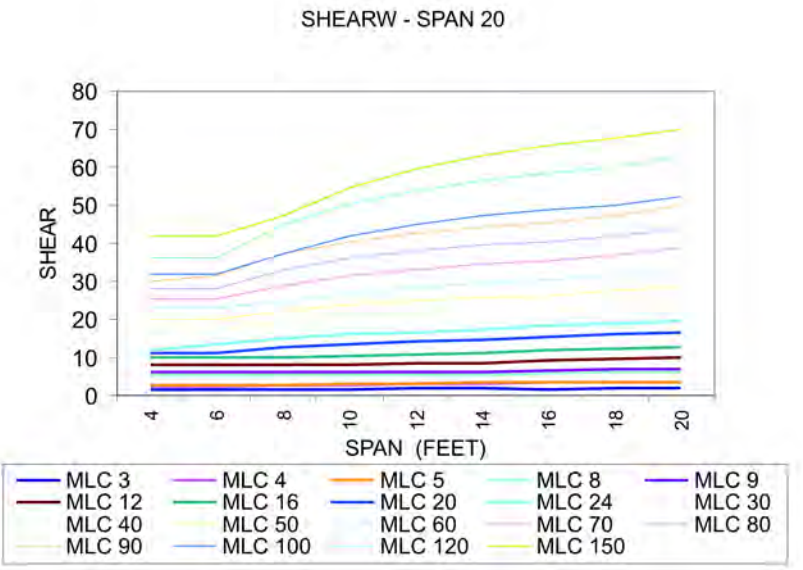


Figure 8.12. Shear W – Span 20.

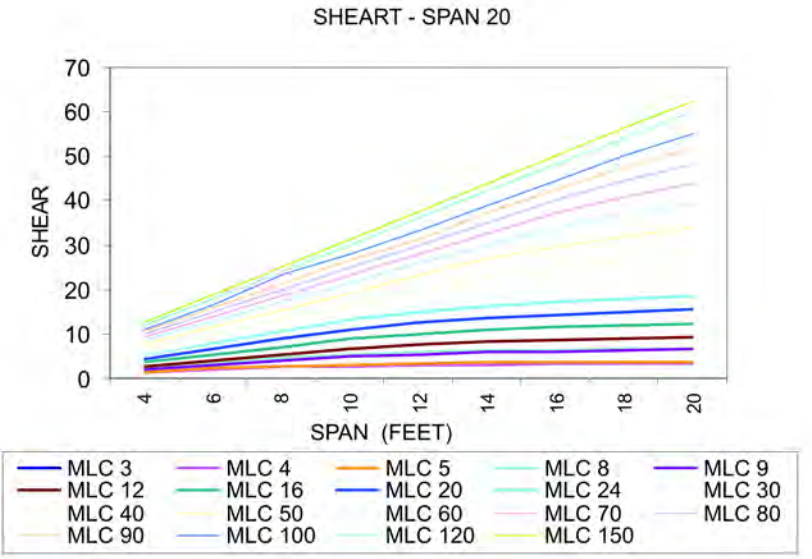


Figure 8.13. Shear T – Span 20.

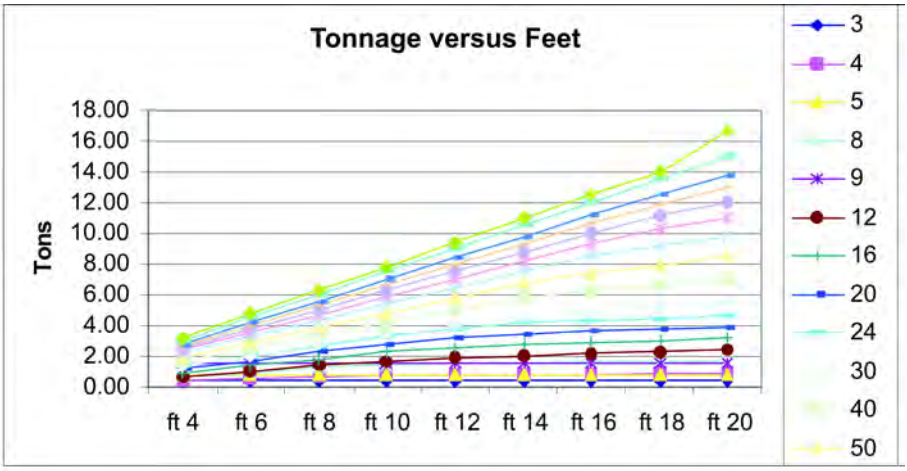


Figure 8.14. Tonnage versus feet.

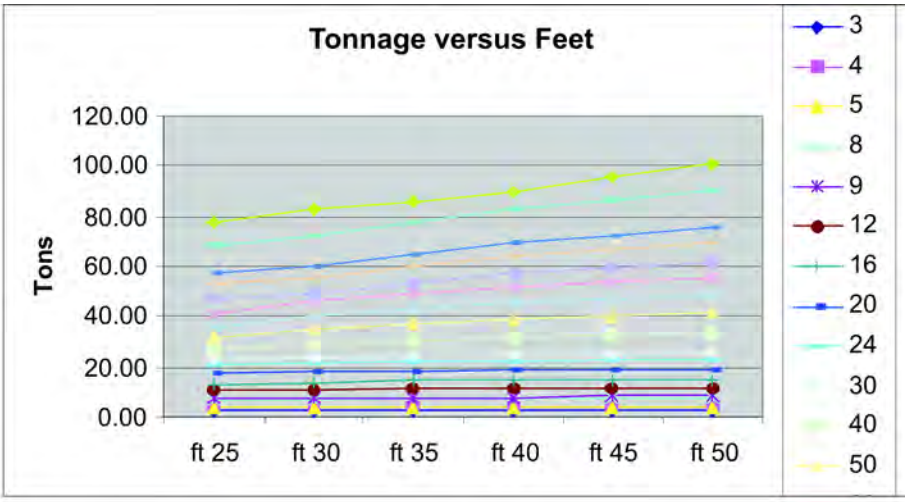


Figure 8.15. Tonnage versus feet.

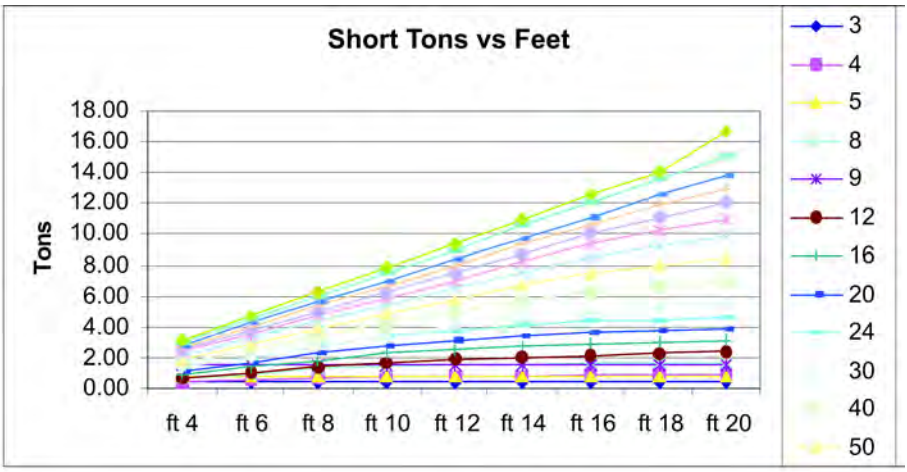


Figure 8.16. Short tons versus feet.

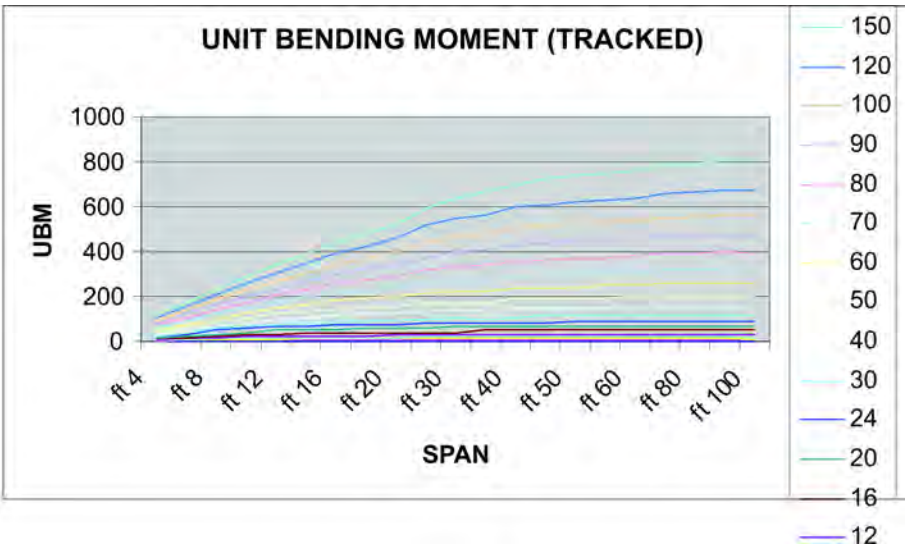


Figure 8.17. Unit bending moment (tracked).

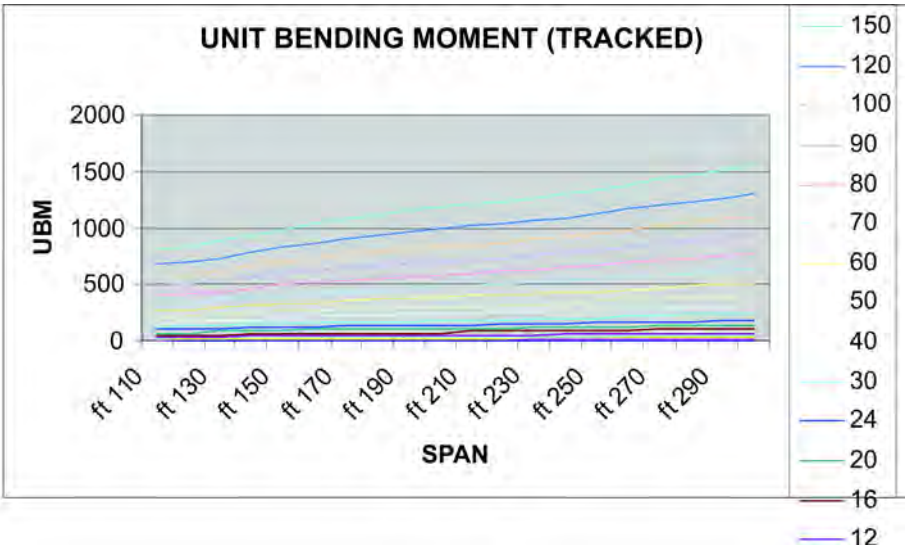


Figure 8.18. Unit bending moment (tracked).

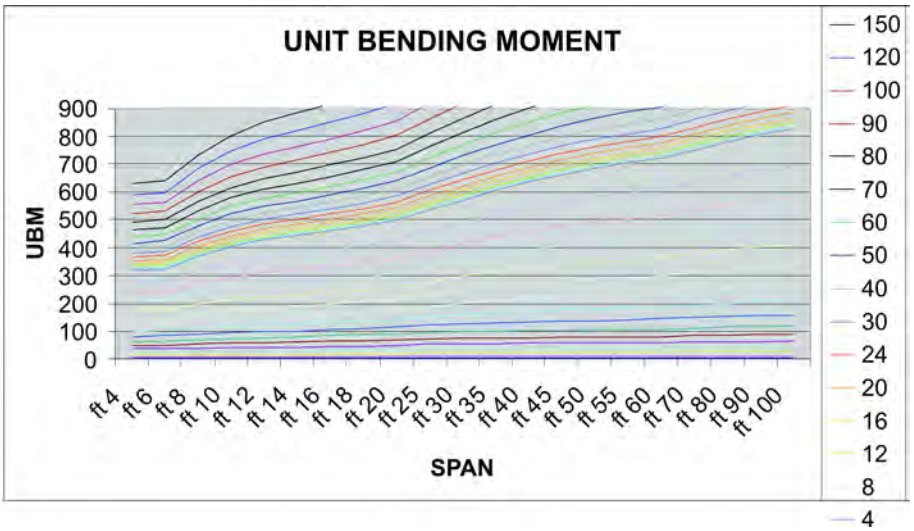


Figure 8.19. Unit bending moment – MLC 8 to 150.

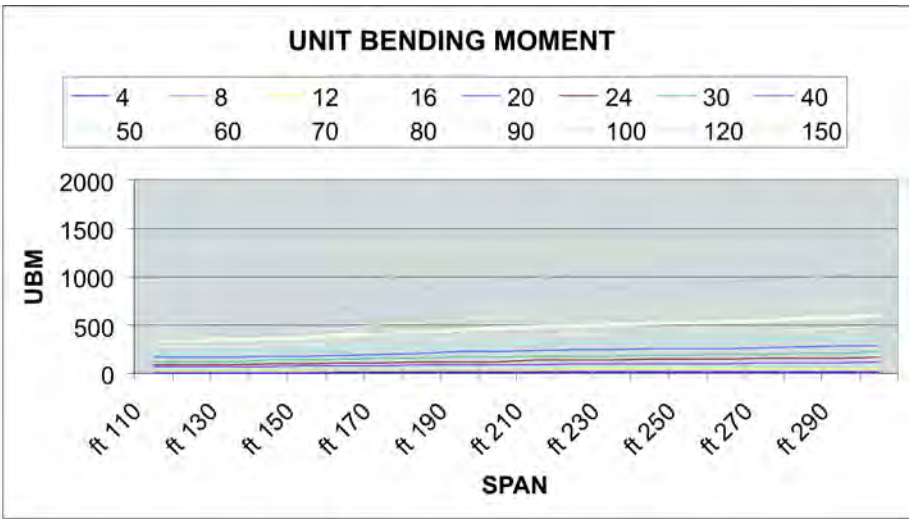


Figure 8.20. Unit bending moment – MLC 4 to 150.

CHAPTER 9

THE FUTURE

We have seen in the first chapter of this Monograph that the history of military bridging is a few millennium years old. Although the face of a modern war has changed considerably, there are a few basic things that do not change that easily. Now the battlefield has become much more complex and changed over to the fourth dimension of space; yet it is still the occupation of ground that becomes vital in the final outcome of any conflict. The obstacles may change dramatically but eventually negotiating those obstacles becomes imperative. Whether it is Bangladesh war of 1971, Yom Kippur War of 1978, War in Kosovo in 1995, or 'Iraqi Freedom' of 2003, crossing of rivers, canals, or obstacles assumes importance at one time or the other. A brief review of the lessons learnt during these operations can throw some light on what direction the technology and its applications for development of military bridging system of the future are heading.

9.1 LESSONS LEARNT DURING RECENT WARS

Although the 1971 Bangladesh war is now over three decades old, it was the most significant war for India since both the adversaries were practically on the same technological level. It was therefore adequate for India to depend upon its World War II vintage bridging equipment. The post World War II equipment that were being imported just before the war from the Soviet Block and West Germany were not even fully integrated into the inventory and were therefore not used. In 1999, the undeclared Kargil war brought to the fore, the need to have a specific infantry-crossing equipment on glaciers and at high altitudes, which themselves were unique in nature. The indigenous equipment that was developed on priority was

one of its kind since no other country had felt a need to have such an equipment. As far as India is concerned, the investment in development of technology of aluminium alloys and lightweight structures came handy to fulfil the Army's requirement in a very short time.

The crossing of Suez canal in the Yom Kippur war of 1978 by the Egyptians Forces brings to the fore the importance of surprise to any river-crossing operation. Over the centuries, the river-crossing fundamentals have remained the same; but their applications vary from case to case. Speed, traffic control, flexibility, extensive preparation are some of the basic factors to be considered for any river-crossing operation; but the most important fundamental is the element of surprise. On that fateful Yom Kippur Day, the Israelis never expected the usual bridging exercise conducted by Egyptians would suddenly turn into an actual assault crossing and the start of a major military action.

The range and lethality of modern weapons allow even a small force to defeat a larger exposed force caught in an unfavourable position. A river provides an ideal opportunity to prove this principle. While the defender would like to take maximum advantage of this situation, the assaulting army, through the element of surprise, can neutralise the defender's advantages. The skillful use of night, smoke, fog, and bad weather can provide a major advantage even in the days of modern information-gathering technologies.

In Kosovo, at the end of 1995, a need was felt to build a bridge across Sava river to re-establish communication and augment the relief operations. The United States, in their assumed role of peacekeeper, allocated about six days to building a pontoon bridge across the Sava river to get into Tuzla, Bosnia. The Army engineers were confident and compared the task with the crossing of Rhine river, across which they had constructed Pontoon bridges several times in the World War II. Yet, six days was too much of a time if relief operations are to be considered as priority. In actual practice, the rains started on the second day of construction swelling the Sava to twice its normal size. Bridge engineers, under the gaze of international TV crews, finally pieced together a 373 foot span using all available equipment. So, it ended up in two weeks,

not one week. What concerned Army strategists was that the Sava crossing was unopposed and the achieved construction time of two weeks was not acceptable in any military operation.

During the 1991 Persian Gulf war, warplanes from the United States, Britain, and France destroyed all bridges across the Euphrates to hinder troop movements ordered by Baghdad. But because alliance forces were expected to occupy Iraq during the Operation Iraqi Freedom of 2003, bridges across the Tigris and Euphrates were critical. The odds were that the United States would blow up every bridge across the Tigris and Euphrates to impair Iraqi military operations or that the Iraqis would destroy the bridges themselves to try to stop the advance of alliance forces. The Pentagon therefore ordered Army and reserve units to practice bridge construction using new equipment that was redesigned following embarrassing mistakes that delayed the US military's entry into Bosnia seven years ago. The Pentagon ordered the design of a so-called improved ribbon bridge (IRB), which began testing in late 2001. The IRB received a rollout ceremony at the Anniston Army Depot in central Alabama on June 4, 2001, as military authorities celebrated the new design. The new bridge, which was engineered by Eisenweke Kaiserslautern in Germany, only increases the weight of vehicles that can traverse its pontoon support system. More than this, there was no major improvement over what the Soviets deployed during the early cold war days. Apart from the IRB, several sets of Mabey bridging equipment were ordered. This too was nothing but an improved version of the age-old Bailey. The MGB was also deployed and short span MGB were emplaced by helicopters, (fig. 9.1). The Wolverine AVLB, recently introduced by the US Army and the BR-90 system introduced by UK were overkill for any of the operations in Iraq and did not find any significant role. This was partially due to the fact that the Iraqis did not destroy any of their existing bridges and the same could be used by the Alliance Forces to carry even the heavy tanks across. The problem envisaged by the military strategists posed by the 1,700 mile long Euphrates never cropped up. Thus, part of network of rivers and lakes that helped make Iraq the cradle of civilisation 8,000 years ago did not pose any major obstacle-crossing problem. During the rainy season of March through May, the Euphrates can be 220 m wide, although it averages about

Figure 9.1. The medium girder bridge is being heli-lifted during Operation Iraqi Freedom.

150 m or so throughout much of central and southern Iraq. This dynamic geographical change can become a major problem for the military planners.

9.2 REVOLUTION IN MILITARY AFFAIRS

A revolution in military affairs (RMA) is a major change in the nature of warfare brought about by the innovative application of new technologies which combined with dramatic changes in military doctrine and operational and organisational concepts, fundamentally alters the character and conduct of military operations. Such an RMA is now occurring, and those who understand it and take advantage of it will enjoy a decisive advantage on future battlefields. During and immediately after the World War I, forward thinking military officers such as Col JFC Fuller of the British Army and Maj Earl Ellis of the US Marine Corps outlined the basic features of armoured warfare and amphibious warfare. They defined these concepts decades before the necessary systems existed and at a time when the political circumstances of the next war were uncertain. In the case of armoured warfare, only the Germans employed tanks, radios, and airplanes in new ways in 1940 even though all of the essential technologies had been available since World War I. This situation was due in part to Germany's unique strategic problem of being surrounded by enemies. This problem led to an operational

requirement for rapid offensives to defeat enemy states quickly, and the emphasis on offense dictated tactical requirements for mobility, firepower, and protection. Germany thus integrated tanks, infantry, and artillery in the Panzer division and supplemented them with close air support. France and Britain constrained by defensive strategic and operational concepts on land, did not innovate and paid the price in May 1940. The importance of the battletank and military bridges was realised only after this shocking experience of the blitzkrieg.

Stephen Rosen of Harvard University has framed the debate on future military competitors by dividing the world into zones of peace and zones of turmoil. His fundamental division of the great powers places the industrialised democracies in the zone of peace with all other countries in the zone of turmoil. Conflicts will most likely arise among nations in the zone of turmoil, or between them and countries in the zone of peace. It is difficult to develop scenarios that lead to wars among nations in the zone of peace. In the context of South Asia, the following issues can assume great importance and such issues will decide the basic difference in the potential nature of the war of the future.

- Historical context
- Geography (landlocked, access to ports, agriculture, terrain, etc.)
- Economic development (trade, industrial base, self-reliance)
- Political system (democratic, autocratic, stability)
- Access to foreign markets and technologies
- Military force structure (disposition, training)
- Nature of alliances (cooperative agreements, traditional/nontraditional adversaries).

The current RMA, like the interwar period, will involve the emergence of multiple new warfare areas. A warfare area is a form of warfare with unique military objectives and is characterised by association with particular forces or systems. Examples of warfare areas that emerged in the interwar period are armoured warfare, carrier warfare, amphibious warfare, and strategic bombing. We see the emergence of four potential new warfare areas as long-range precision strike, information warfare,

dominating manoeuver, and space warfare. Of the four potential new warfare areas, analysis of dominating manoeuver is relevant when one considers military bridging as ones main focus.

9.3 DOMINATING MANOEUVER

The dominating manoeuver is defined as the positioning of forces integrated with precision strike, space warfare, and information war operations to attack decisive points, defeat the enemy's centre of gravity, and accomplish campaign or war objectives. In the early 19th century, Clausewitz made similar observations when discussing the formulation of successful strategy. He wrote that victory comes not through winning battles or inflicting attrition but through attacking the enemy's centre of gravity, which depending on the situation could be his army, his capital, his leaders, or his principal ally. To execute dominating manoeuver in 2020, the nation will have to develop new means for the movement of ground forces. The development of forms of mobility not possessed by the enemy could help generate manoeuver dominance. The dual imperatives of mobility and logistics may create the need for smaller forces and new transportation technologies. The current strategic mobility needs will demand the ability to move a corps equivalent force across the oceans in seven days or less. In the Indian context, this would convert into ability to move quickly from one theater to another. Today for a major military power, it takes the intercontinental deployment of a heavy brigade 15 days and a heavy corps 75 days. This is not simply acceptable in future.

With increasing complexity, the nonlinear nature of war is likely to increase. Dominating manoeuver seeks to exploit the increasing complexity and nonlinearity in warfare. What role military bridging equipment will play in this scenario is unclear at present. However, restricting ourselves to the Indo-Pak conflict, the ground realities are not likely to change that rapidly. The perpetual border disputes and tension will make holding of the ground at strategic positions all that important. Because that will eventually determine the 'Line of Actual Control', and consequently the 'International Border'. The future course of development to be followed for the Indian military bridging equipment therefore need not necessarily follow the same path as is being followed by the major powers in their new peace keeping

role. We will revert back to the Indian context after having an overview of the latest developments in the developed world.

9.3.1 New Bridges for a New Century

Strategic and tactical mobility has risen high on the agenda as armies around the world find that their cold war vintage bridging systems are not up to the challenge of the new world disorder. Armies are having to make do with fewer people, so technology is being applied to reduce the number of men needed to build military bridges. Secondly, the burgeoning of peace keeping and humanitarian operations in the Balkans has exposed the limitations of many of the bridging systems currently in some inventories.

The British Army has adopted the Vickers Defence Systems BR90 bridging system for use on its Chieftain AVLB, giving it a capability to lay a 26 m bridge. A programme is underway to migrate the single-folding scissors bridge onto a Challenger chassis. This technology has been transferred to Hyundai in South Korea for use on the K1 tank. Giat Industries have adopted the BR90 bridge for use on Leclerc tanks and has proposed the solution to the French Ministry of Defence. Vickers Bridging Systems, recently taken over by Alvis, who will develop the bridging system.

Germany's MAN Technologie AG is a strong competitor on the armoured bridge layer market with its Leguan bridge. It uses a horizontal deployment system. The US Army have adopted the 26 m bridge as its Wolverine heavy assault bridge (HAB) for use on a M1A1/A2 Abrams tank chassis. General dynamics land systems are the US prime contractors on the Wolverine programme, although this is in question after the US Army reviewed its bridging programme in late 1999. In cooperation with the Company's parent, Krauss-Maffei Wegmann, the Leguan has been installed on a Leopard 1 chassis and is in use with the Norwegian and Belgian Armies. Peugeot Espana has co-developed a M60-mounted version for the Spanish Army. In early 1999, the Dutch and German Armies contracted the Company to develop a prototype bridge-laying tank based on a Leopard 2 tank by 2001. This is based on the Company's new modular bridge system, that uses three 9.7 m spans.

In the category of heavy dry support bridge, Sweden's Kockums Karlskronavarvet, a Celsius subsidiary, has developed versions of its Fast Bridge (FB) family of products. The 40 m bridge, that uses a launching rail or beam supported by a mechanical building system, is constructed by a seven strong crew in 90 min. Britain's William Fairey Engineering has also developed a rail-launched 42 m bridge that can be built by eight men in 40 min. A mechanised building system lifts palletised bridge sections from a truck and then launches them across the rail. Vickers Defence Systems has developed the BR90 system for the British Army requirement to replace its veteran MGB. BR90 uses an automative bridge launching system (ABLE), to allow a 32 m gap to be crossed with a single span in less than 25 min, using a ten strong crew. A launch rail is projected across the gap and bridge sections are then mechanically moved. A 62 m two-span bridge, that can be created using a pontoon or pier, has also been accepted into British Army service. A 44 m bridge is soon to enter service on British Army ABLE design. Vickers is working on private venture developments on rafts, pontoons and new versions of the BR90.

9.3.2 Wet Bridging

EWK Eisenwerke Kaiserlautern GmBH are the major players in the wet bridge market with their M2 and new M3 amphibious bridges and fast-folding bridges. The M3 amphibian is a mobile and flexible system, that allows self-deployment to a crossing point. Once in the water, the amphibian can be anchored with other vehicles to form a bridge, or using its own internal propulsion to act as a ferry. The Company's fast-folding bridge is designed around a number of floating modules, that can be anchored to form a bridge or used as a ferry. A single set can create a 135 m bridge or a number of smaller bridges. The system is not powered and requires tug boats to construct bridges in fast-flowing rivers. An improved version, the fast-folding bridge II, has been designed and tested to meet German Army requirement to carry a standard 70 ton load. FFB 2000 is the MAN Technologies' ribbon bridge that uses floating sections to create bridges or ferries. The US Army's improved ribbon programme got underway in January 2000 with the delivery of proposals to TACOM from the two contending teams, prior to a programme of testing.

Figure 9.2. A bridge system during developmental trials.

The requirement is to increase the load-carrying capability of the bridge and its ability to withstand the forces coming in from fast-flowing rivers. This bridge was readied for operational use in the Operation Iraqi Freedom in 2003. United Defence and Systems Electronics Inc. is offering a home-grown American product for the US Army's improved ribbon contest. The French company CNIM, produces a family of bridges across the tactical spectrum. Its PFM ribbon bridge modules can be used either as bridges or as ferries. India's Defence Research & Development Organisation (DRDO) has recently come up with a technology demonstrator prototype of a ferry which would prove a cost-effective solution as compared to the floating bridges now in use. Figure 9.2 shows such a system during developmental trials.

9.3.3 Rapid Deployment of Military Bridges

The present worldwide trend in military bridging is towards the development of rapid deployment forces. Future operations will remain complex even in case of asymmetrical conflicts or against small and weak nations. Rapid deployment forces can attain a high operational level only through a good synergy between their components. The need for engineer support for these forces is obvious and primary for their mobility.

The main characteristic of rapid deployment forces is definitely their mobility, strategic as well as tactical. The capability of the relevant

equipment to cross obstacles is less demanding than that of heavy equipment. Thus, there is a need to equip light forces with bridges.

An assault bridge for rapid deployment forces must be easily air-transportable and so its weight and dimensions should be reduced to a minimum. However, strategic mobility is not just the intercontinental mobility, but equally land mobility in the range of hundreds of kilometer. Only wheeled vehicles have the necessary mobility. Technical progress has significantly improved cross-country performance of wheeled vehicles to similar levels of those of tracked vehicles. The modularity of the rapid deployment bridge is intended to give good crossing capability together with reduced dimensions. The modularity is the ability to carry several short bridges and to combine them at the time of their launching to attain the required length of the bridge. A wheeled modular bridge is then the more efficient assault bridge for rapid deployment forces.

With regard to floating bridges, the lower weight of the fighting vehicles will reduce the buoyancy necessary but the floating bridge must still necessarily be of relatively large dimensions, since its load-bearing capacity is defined by Archimedes principle. This will then be a constraint for air lifting. A ferry will always be more easily transportable by air than a bridge with regard to the number of pieces of equipment.

9.3.4 Military Bridging–organisational Issues

Current bridging organisation with most armies depends upon engineer regiments or bridging companies. These are tailored around their specific floating, fixed span or assault bridging equipment. Each unit holds one of the equipment of the above type and specialises in all operations connected with that equipment. Not only training, but the bridging and logistics support equipment is also specific to the bridging equipment that the regiment specialises in. Thus, bridge erection boats, transportation trucks, earth moving equipment, etc are specific to the unit. This specialisation is at the expense of flexibility in operation. When different types of bridging equipment are needed for a particular operation, more number of specialised units are required to be deployed. This major shortcoming in the organisational structure is being overcome through deployment of multi-role bridging companies, especially by the US Army.

The multi-role bridging company (MRBC) is a combination of bridging companies holding fixed-span, floating, and assault bridges. A typical operational mission would begin with a platoon responding to a mission with an initial basic load of the desired bridge. When it completes the first mission, the platoon moves to the next site, either picking up the next required bridge along the way or finding the bridge cached at either the engineer bridge park or the site it will be emplaced. As the forces advance, the bridges become the responsibility of the engineer units in the communication zone. As prefabricated bridging/assault bridging is replaced by the more permanent bridging, the platoon responds to bridge-retrieval missions.

The MRBC's capabilities will give Commanders the ability to quickly manoeuver and respond, through either fixed or floating bridging or combination of bridging systems most appropriate to a particular mission. The major impact of MRBC will be the flexibility of operation and inventory that will enable the Army to regroup at short notice and thus help achieve dramatic effects of a quick manoeuver. In the Indian context, this can bring in a major transformation in operational planning.

9.4 FUTURE – THE INDIAN SUBCONTINENT

The conflicts in the Indian subcontinent have always centred around the unsettled border disputes that could not be peacefully resolved during partition. As a result, Indo-Pak border has continuously remained as a flash point between the two countries. Although major international issues such as Kashmir cannot be resolved by force, holding of the ground to stake claims eventually on the Line of Actual Control has always remained on the top of the agenda in planning any offensive or defensive operation. The Himalayan mountains and valleys, rivers originating from these, and extensive network of irrigation canals that have been existing for over 100 years by now, provide a natural setting that is a challenge to any combat operation in the world. Add to these, the extreme climatic conditions and altitudes, avalanches, glaciers, and floods in rainy season. It would appear that it is not possible to imagine any kind of conflict in such extreme and harsh conditions. Yet, the 1962 Chinese aggression has taken place at the beginning of the winter. Also

the operations at Siachen glacier and at the Kargil heights have taken place at altitudes higher than 6000 m where only mountaineers dare to climb as a part of their adventures and expeditions.

In the plains of Punjab and Rajasthan, it is a different story. As the natural features such as rivers are not enough and the age-old irrigation canals provide only a limited defence, both sides have found it necessary to construct a new type of obstacle DCB close to the actual international border. The concept was to dig out the sand along a belt of several kilometers and dump it on one side to form a mound, which eventually is given a suitable shape to accommodate concrete pill boxes and a track for movement of a jeep-mounted gun. Such a DCB eventually runs across most of the border length spanning hundreds of kilometer to pose a formidable defence against the assault from the adversary. Mere magnitude of such an obstacle makes it practically impossible to attack with full strength across any desired point, thus making it imperative for both sides to leave certain gaps with minimal defence where the obstacle-crossing is least expected. This is where the natural ground conditions play an important part. For example, a DCB in embankment provides a formidable defence due to the need on either bank for having approaches and exits apart from gap crossing bridging equipment. In fact, at many probable crossing points, the entry and exit are extremely difficult, while crossing the main ditch, whether wet or dry, is comparatively easier. Add to this, the minefield and possibility to waterlog the entire approaches, which are already strewn with burrow-pits. One encounters a formidable obstacle that no standard bridging equipment in the world can negotiate in acceptable time frame.

The obstacle-crossing operation in the Indian context becomes much more complex than crossing a river in Europe and would need a system of systems with elaborate organisation and planning. This is where the technology can help the aggressor if he can use it with advantage. After all, the equipment has to be designed to fit into multifarious roles such as fixed bridge, floating bridge, multi-span bridge, approach ramp, and so on. If a family of bridging systems is built around the advanced technologies,

as described in Chapter 7, it can provide a cost-effective solution through the use of a family of bridging systems, operating in unison and with close support from air and other ground forces. The net effect of this would be a total surprise, making it possible for the forces to cross at points least expected for an assault operation. This would be ultimately resulting in achieving dominance in manoeuver that is so very essential in a quick and short modern war.

On the ground, this can be explained as widening the front. Today, both the adversaries consider some portion of the border as a zone of peace, since none of them are capable of achieving an assault crossing operation in those regions, simply because they do not have equipment to negotiate such a formidable obstacle in acceptable time frame and using affordable resources. If however, one side has a capability to negotiate such an obstacle through the deployment of technology and tailor-made equipment, it can prove to be a force-multiplier, and eventually a winning edge in the highly competitive field of a modern war. That goes to prove that in the field of military bridging, there is no single solution for every theater and that individual players can have the winning advantage provided they have a meticulous technology and equipment planning with a dynamic organisational structure.

9.5 CONCLUSION

Emergence of a number of bridging systems in the post-cold war period, especially by the traditional leaders in the field, is a clear indicator that military bridging has a definite future in the future wars, whether it is in the middle east or in a far corner of southeast Asia. Indo-Pak conflicts in the past are clear indicators to show how obstacle-crossing will hold a key in the future. While technology is driving some of the applications, operational compulsions will determine the choice of technology, equipment, and tactics in most cases. Apart from these considerations, bridges have a place in the society and the national development. Military technologies can definitely make the future bridges in the world not just civil engineering structures; but as smart and intelligent structures that can help the process of development worldwide through new revolutionary

concepts in communications. The investments in military systems of the past can help achieve these objectives in the decades to come. There are sufficient indicators, which have already reached the demonstration phase to support this hypothesis.

GLOSSARY

AO	Area of Operation
ASD	Allowable Stress Design
ASTM	American Society for Testing Materials
APL	Anti-personnel Landmine
AVLB	Armored Vehicle-launched Bridge
AAB	Armoured Assault Bridges
ABLV	Armoured Bridge Laying Vehicle
AFV	Armoured Fighting Vehicle
AER	Assault Engineer Regiment
ABLE	Automative Bridge Launching System
BEB	Bridge Erection Boat
BOM	Bill Of Material
BRO	Border Roads Organisation
BLT	Bridge Layer Tank
BTC	Bridging Training Camp
CLMC	Charged Line Mine Clearance
CET	Combat Engineer Tractor
CES	Complete Equipment Schedule
CAD	Computer Aided Design
DICE	DARPA Initiative in Concurrent Engineering
DP	Decision Points
DARPA	Defense Advanced Research Projects Agency
DTRA	Defense Threat Reduction Agency
DCB	Ditch-Cum-Bund
EME	Electrical and Mechanical Engineers Establishment

EBC	Experimental Bridging Company
EBE	Experimental Bridging Establishment
FMEA or FMECA	Failure Mechanism Evaluation and Criticality Analysis
FASCAM	Family of Scatterable Mines
FB	Fast Bridge
FM	Field Manual
FEA	Finite Element Analysis
HAZ	Heat Affected Zone
HAB	Heavy Assault Bridge
IRB	Improved Ribbon Bridge
IRC	Indian Roads Congress
ILS	Integrated Logistics Support
ISO	International Organisations for Standardisation
LCC	Life-Cycle Cost
LRFD	Load and Resistance Factor Design
LSA	Logistics Support Analysis
MAG	Maintenance Advisory Group
MLAB	Manually Launched Assault Bridges
MRP	Manufacturing Resource Planning
MTBF	Meantime Between Failure
MTTR	Meantime To Repair
MGB	Medium Girder Bridge
MEXE	Military Engineering Experimental Establishment
MLC	Military Load Class
MVEE	Military Vehicles and Engineering Experimental
MRBC	Multi-role Bridging Company
PDM	Product Data Management
PTO	Power Take Off
QFD	Quality Function Deployment
RPMC	Requirements for Polymer Matrix Composite
RMA	Revolution in Military Affairs
SPC	Statistical Process Control procedures

STANAG	Standard Agreement (NATO)
TAI	Target Areas of Interest
TM	Technical Manual
UBM	Unit Bending Moment
WMD	Weapons of Mass Destruction

INDEX

A

Abatis 13
Abrahams-based Wolverine 162
Allowable stress 49
Aluminum standards and data 113
Amphibian vehicle 38, 149
Amphibious dozer 38
Amphibious reconnaissance equipment 35
Ancillary equipment 35
Applied loads 49
Armoured assault bridges 39
Armoured bridge laying vehicle 15
Armoured vehicle launched bridge 162, 175
Assault crossing 148
Assault Engineer Regiments 39
ASTM E399 58
Automative bridge launching system 248
Availability 49, 108

B

Bailey bridging 5, 30, 145, 154
Bank conditions 65
Bearing contact (Hertz) stress 49
Border road network 173
Bridge layer tanks 7
Bridges during World War II 145
Bridging training camps 141
Buckling stress 49
Bunkers 12
Buy 131

C

Caution crossing 111
Charged line mine clearance 15
Churchill tank 29, 30
Civil applications 169
Civil bridges 169
Cold War 147, 148
Combat engineer tractor 12, 15, 154
Combat missions 11
Combined stresses 82
Complete equipment schedule 131
Component testing 109
Composite materials 189
Concertina coil 14
Concurrent engineering 198
Corrosion codes 113
Corrosion resistance 58
Countermobility devices 13

Abatis 13
Concertina coil 14
Mines 14
Simple obstacles 13
Creep behavior 63
Criticality analysis 133
Crossing means 21
Crossing obstacles 30

D

Damage-tolerant design 90
Defect report 132
Depot maintenance 138
Design 43
Design interface 141
Design load 49
Design parameters 64
Ditch-cum bund 7
Dominating manoeuvre 246
Double-storeyed bridges 134
Draw bridge 175
Duralumin 176

E

Economic considerations 106
Emergency numbering system 180
EN series steels 180
Erectable bridges 148

F

Failure 50
Failure mechanism 133
Fatigue 88
Fatigue constructions 106
Fatigue design life 50
Fatigue design load range 89
Fatigue properties 61
Ferries 30, 32
Fighting positions 12
Bunkers 12
Foxholes 12
Revetments 12
Trenches 12
Finite element analysis 180
Fixed bridge MLC 3 144
Floating bridges 32, 166
Foot walk 65, 79
Fording mat 31
Fording vehicles 149
Fords 30
Foxholes 12

G

Ground handling equipment 140

H

Hasty river-crossing 41
Heavy rafts 149
Hedgehogs 13
History of military bridging 5
House of quality matrix 200
Hypothetical vehicles 76

I

Improved float bridge 150
Improved ribbon bridge 243
Indian GRSE bridge 173
Indigenous equipment 132
Infantry bridges 144
Infinite life 93
Integrated logistics support 136
Integrated product development

142
Interior bay 153
Intermediate level maintenance 138

K

Kartik 157
KMT-6 bridge 166

L

Leonardo da Vinci sketch 3
Leopard-based Leguan 162
Life-cycle cost 136
Lifting and anchorage safety 86
Limit state design 84
Load and resistance factor design 187
Load combinations 76
Loads 76
Logistics 131
Logistics cost 136
Logistics support analysis 136

M

Mabey bridges 173
Maintainability 108
Maintenance Advisory Groups 137
Maintenance concept 110
Maintenance planning 138
Maltilda 29
Manually launched assault bridges 157
Mean time between failure 138
Mean time to repair 138
Medium girder bridge 134, 157
Metal data chart 114
Metal data sheets 113
Military bridge classification system 203
Military bridge loads 76
  Dead load 76
Military bridging 5, 35
  Curbs 79
  Design 44
  Foot walk 79
  History 5
Mine categories 21
  Anti-personnel mines 21
  Anti-tank mines 21
Mines 14, 40
Minimum freeboard 74
Mission cycle 51
Modification 106
Mountain warfare 154
MTU-20 AVLB 162

N

NATO 45, 147
Normal crossing 111

O

Obstacle control measures 19
  Obstacle belts 20
  Obstacle groups 19
  Obstacle zones 20
Obstacle effect 18
Obstacle planning 16
  Fire support 16
  Intelligence 16
  Logistics 16
Obstacle zones 20
Obstacles 17, 40
Obstacles categories 17

Existing obstacles 17
Reinforcing obstacles 18
Phony 18
Protective 18
Tactical 18
Offensive operations - mobility 15
Breaching minefields 15
Bridging 15
Clearing obstacles 15

P

Performance tests 94
Phony obstacle 18
Pier load 81
Piers 72
PMP/PMS Pontoon bridge 169
Pneumatic assault boats 149
Ponte Vecchio 2
Pontoon bridge 6, 175
Post-buckling strength 186
Preliminary working stresses 55
Product data management 140
Power take off 178

Q

Quality function deploymen methodologies 135, 199

Quality systems 132

R

Rafts 6
Ramp bay 153
Ramp-elevation ranges 73
Reinforcement kit 157
Relieving girders 169
Requirements for polymer matrix composite 48
Revetments 12
Revolution in military affairs 242
Ribbon bridge 150
Ribbon bridge
Equipment launch
Controlled 150
Free 150
Helicopter delivery 150
High bank 150
Method 150
Risk crossing 112
River-crossings 40, 148
Deliberate 41
Hasty 41
Tactical bridging 41

S

Safety 82
Sarvatra 166
Scissor launch 176
Scissors assault bridge 154
Simple obstacles 13
Site selection 150
Situational obstacles 20
Slope 129
Software development 110
Spectrum of logistics 131
Stanag 2021 76, 203
Statistical process control procedures 132
Stress derating 109
Stress rupture 61
Structural strength tests 94

Supply support 140
Suspension bridge 6

T

T-72 based bridge layer tank 162
Tactical bridging 41
Tatra chassis 177
Tension 83
Testing 93
TMM-3 bridge 166
Torsional-flexural buckling 187
Trafficking tests 99
Training support 141
Trenches 12
Trestle-cum-span bridge 175
Truss bridges 154
Typical configurations 146

U

Ultimate stress 52
Unit bending moment 213
User trials 94

V

Variable-amplitude loading 187

W

Welding 184

Y

Yield stress 53

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About the Book

The Monograph on Military Bridging bridges the gap that has somehow crept in over the years between the acquisition of different types of Combat Engineer Equipment and availability of comprehensive reference material that can establish a relationship between these equipments. The large inventory, though always felt as too inadequate by the user, has to be seen in the larger sense of developing tactics and doctrines around them. Also most important factor is the dynamic battlefield that can pose different problems at different times. Therefore, one has to have an innovative solution to select the equipment in a non-traditional manner. The way the technological developments are rapidly taking place, new solutions must emerge at shorter intervals. Thus the User 'Pull' and Technology 'Push' should produce dramatic results.

This Monograph is not a panacea for all these problems. It only attempts to put the things together so as to enable a knowledgeable user to find a common thread from the age old battles to the future. Of particular importance will be the material technologies, design codes and integrated logistics support. In the process, if the reader gets some useful guidance and information from this book, the purpose will be well served.

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