BUREAU OF INDIAN STANDARDS
GUWAHATI BRANCH LABORATORY

"DETERMINATION OF MEASUREMENT UNCERTAINTY OF NOMINAL MASS, TENSILE STRENGTH, YIELD STRESS, RIB AREA IN IS 2062:2011 AND IS 1786:2008."

In partial fulfilment for the award of the degree of

BACHELOR OF TECHNOLOGY

FROM

DEPARTMENT OF

CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, BHUBANESWAR

PREPARED BY: KARTIK JAISWAL

22CE01047

DECLARATION FROM THE AUTHOR

I, Kartik Jaiswal (Roll No. 22CE01047), hereby declare that this internship report entitled **"Determination of Measurement Uncertainty of Nominal Mass, Tensile Strength, Yield Stress, and Rib Area in IS 2062:2011 and IS 1786:2008"**
is the outcome of my own work carried out in the Department of Civil Engineering, IIT Bhubaneswar, during the internship period.

All ideas, analyses, and conclusions presented herein are articulated in my own words. Wherever information has been taken from published or unpublished sources, these have been duly cited and referenced in accordance with academic standards and institutional guidelines.

I further affirm that:

1. I have maintained the highest standards of academic honesty and integrity in the preparation of this report.
2. I have neither fabricated nor manipulated any data, results, or sources.
3. No portion of this report has been submitted for any other degree or qualification, either at this institute or elsewhere.
4. Permission has been obtained for inclusion of any proprietary or confidential information, and appropriate acknowledgements are provided.

I understand that any violation of these declarations may render this report invalid and may invite disciplinary action under the institute's regulations.

Place: BIS Guwahati Branch Laboratory
Date: 18 June 2025

Kartik Jaiswal
Intern, Department of Civil Engineering
IIT Bhubaneswar

22CE01047

SIGNATURE

ACKNOWLEDGEMENT

With heartfelt gratitude, I acknowledge the invaluable support and guidance I received throughout my internship and the preparation of this report. I am especially indebted to Ms. Thechano, Officer-in-Charge of the Testing Laboratory, whose expert supervision and unwavering patience in demonstrating test setups, clarifying procedural details, and ensuring safe operation of all instruments were instrumental in my understanding of tensile and rib-area measurements. I also extend my sincere thanks to Mr. Rahul, Officer-in-Charge of Quality Assurance, for his meticulous scrutiny of experimental protocols, insightful feedback on data analysis, and steadfast encouragement to uphold the highest standards of accuracy and reproducibility.

My appreciation goes to lo- **Mandeep Singh** Sir for his efficient coordination of laboratory schedules, timely calibration of equipment, and readiness to troubleshoot technical issues at a moment's notice. I am truly grateful to Mr. **Pritam Kumar Sharma** and Mr. **Neeraj giri** for their patient assistance as teaching assistants—always available to guide me through complex procedures, answer my many questions, and share their hands-on expertise in material testing.

I would also like to thank the CDC IIT BBS, and all faculty members of the Department of Civil Engineering, IIT Bhubaneswar, for their valuable advice and for fostering an environment of curiosity and collaboration. My thanks extend to the technical staff of the Civil Engineering workshop and the fellow interns whose camaraderie and constructive discussions enriched this learning experience.

KARTIK JAISWAL

22CE01047

SIGNATURE

19/07/25

OIC (TESTING)

THECHANO C. OVUNG

SCIENTIST-D

OIC(QA)

RAHUL ROY

SCIENTIST-B

ABSTRACT

The present study delivers a comprehensive evaluation of the **measurement uncertainty** associated with the determination of **nominal mass**, **tensile strength**, **yield strength**, and **rib area** of reinforcement bars manufactured in accordance with **IS 2062** and **IS 1786** standards. A robust experimental program was executed, encompassing over **90 specimens** across both steel grades, complemented by a focused uncertainty analysis on **15 representative samples**. Physical dimensions and mass were recorded using precision callipers and analytical balances, while mechanical properties were assessed via a calibrated Universal Testing Machine under controlled laboratory conditions.

Uncertainty contributions were systematically quantified following the **Guide to the Expression of Uncertainty in Measurement (GUM)** framework, incorporating both **Type A** (statistical repeatability) and **Type B** (instrument calibration, environmental influences) components. The Welch–Satterthwaite method was employed to compute effective degrees of freedom, and appropriate coverage factors were applied to achieve a 95 % confidence level.

Results demonstrate that the expanded uncertainty varies notably between the two grades, reflecting differences in material heterogeneity and manufacturing processes. This investigation not only reinforces the criticality of rigorous uncertainty evaluation in material testing laboratories but also provides a transparent, traceable methodology for regulatory compliance and quality assurance. The insights gained herein are poised to inform best practices in structural design, ensure reliability in safety-critical applications, and foster continual improvement in steel reinforcement testing protocols.

PREFACE

This report presents the findings of my internship project titled **"Determination of Measurement Uncertainty of Nominal Mass, Tensile Strength, Yield Stress, and Rib Area in IS 2062:2011 and IS 1786:2008"**, conducted at the Bureau of Indian Standards, Guwahati Branch Laboratory (GBL). Throughout this internship, I have applied metrological principles and material-testing methodologies to rigorously quantify the uncertainty associated with critical mechanical properties of structural steel, in strict accordance with both Indian standards and their international counterparts (ISO 6892-1:2019).

The primary objective was to identify and evaluate all significant sources of measurement error—spanning instrument calibration, specimen geometry, environmental factors, and data processing—and to compute combined and expanded uncertainties using the Guide to the Expression of Uncertainty in Measurement (GUM) framework. Under the expert guidance of the Testing Laboratory and Quality Assurance teams at BIS Guwahati (GBL), I gained comprehensive hands-on experience in precision weighing, dimensional measurement, Yield and tensile testing.

I trust that the methodologies and insights detailed herein will serve as a valuable reference for engineers and researchers engaged in precision testing of construction materials, and will bolster the quality-assurance protocols within both academic and industrial laboratories.

TABLE OF CONTENT

CHAPTER 1: INTRODUCTION

1.1 HSD STEEL BARS

HSD STEEL BARS (IS-1786 (2008)): A Detailed Overview

High Strength Deformed (HSD) steel bars are reinforcement bars that have lugs, ribs, or projections on their surface. They are produced through a process known as cold twisting, which imparts the character deformations.

Key Features of HSD Steel Bars

- **Enhanced Bond with Concrete:** HSD bars have specially designed surface deformations or ribs that provide a strong mechanical interlock with concrete. This enhances the bond strength significantly compared to plain bars, allowing stress to be effectively transferred from concrete to steel. The improved bond minimizes slippage under load and is especially beneficial in critical areas such as seismic zones or heavily loaded structural elements, improving the durability and safety of reinforced concrete structures.

- **Higher Tensile Strength:** High Strength Deformed bars offer superior yield and tensile strength, typically starting from 415 MPa and going up to 600 MPa, depending on the grade. This enables structural components to resist higher loads with less steel, resulting in lighter and more economical designs. The high tensile strength ensures that the bars undergo sufficient deformation before failure, providing ductility and energy absorption in load-bearing applications, which is essential for safety during overloading or earthquakes.
- **Reduced Fabrication Requirements:** Due to their consistent quality and excellent ductility, HSD bars are easier to bend and cut without the need for specialized heating or welding. This simplifies fabrication and reduces on-site labour and installation time. The bars maintain their mechanical properties during bending and shaping, allowing for faster construction and lower fabrication costs without compromising strength or performance.
- **Uniform Deformations:** The surface ribs on HSD bars are manufactured using precision-controlled rolling processes that ensure consistent spacing and height along the entire length of the bar. These uniform deformations result in consistent bonding with concrete and reduce the risk of weak zones where stress concentration or slippage might occur. This uniformity plays a key role in maintaining predictable structural performance under varying load conditions.

- **Available Sizes:** HSD bars are manufactured in a wide range of diameters, typically from 6 mm to 40 mm, catering to diverse structural needs. Smaller diameters are used in slabs and stirrups, while larger ones are suited for columns, beams, and foundations. This availability allows engineers and contractors to choose the most suitable size for each structural component, optimizing both design flexibility and material efficiency.

Key Features of HSD Steel Bars

HSD (High Strength Deformed) steel bars work by enhancing the tensile capacity of reinforced concrete structures. While concrete is strong in compression but weak in tension, HSD bars are embedded within it to resist tensile forces. Their surface deformations (ribs) create a strong mechanical bond with concrete, preventing slippage under load. When the structure is stressed, the concrete handles the compressive forces, and the HSD bars carry the tensile loads. This combined action ensures greater structural stability, improved load-bearing capacity, and enhanced safety, especially in seismic or high-load conditions.

Advantage of Using HSD Steel Bars

1. **High Strength and Improved Structural Integrity**: HSD bars offer high yield and tensile strength (Fe 415 to Fe 600), allowing structures to resist greater loads with less steel. This enhances overall structural integrity and makes them ideal for both heavy and high-rise constructions.
2. **Enhanced Bonding and Ductility**: The surface ribs ensure superior grip with concrete, minimizing slippage. Combined with high ductility, HSD bars can undergo significant deformation before failure, improving safety and performance, especially under dynamic or seismic loads.
3. **Cost-Effectiveness**: Their higher strength-to-weight ratio allows for the use of smaller diameters, reducing steel consumption. Additionally, ease of bending and cutting reduces on-site labour and fabrication costs, making them economically beneficial.
4. **Corrosion Resistance and Long-Term Durability**: Manufactured with improved resistance to corrosion, HSD bars ensure long-term durability, even in aggressive environmental conditions, leading to lower maintenance and extended service life of structures.
5. **Versatility in Application**: Suitable for a wide range of structures — from residential buildings to bridges, dams, and industrial foundations — HSD bars provide design flexibility and consistent performance across diverse construction needs.

Application of HSD Steel Bar

- **Reinforced Concrete Structures**: Used in beams, columns, slabs, and footings in residential and commercial buildings.
- **Bridges and Flyovers**: Ideal for high-load and long-span structures.
- **Dams and Retaining Walls**: Provide strength and durability in massive concrete structures.
- **Industrial Sheds and Foundations**: Used in large-scale industrial projects for structural framing and base reinforcement.
- **High-rise Buildings**: Suitable due to their high strength-to-weight ratio.
- **Infrastructure Projects**: Used in metro, railway, highway, and airport constructions.
- **Seismic-Resistant Structures**: Widely used in earthquake-prone areas for safety and resilience.

Grades and Designation HSD Steel Bar

Fe 415: Minimum yield strength: 415 MPa; standard ductility for general RCC work.

1. **Fe 415D / Fe 415S**: 415 MPa with **D** (enhanced ductility) and **S** (seismic) variants for improved deformation capacity or earthquake resistance.
2. **Fe 500**: Minimum yield strength: 500 MPa; higher strength than Fe 415 for more demanding applications.
3. **Fe 500D / Fe 500S**: 500 MPa with **D** (enhanced ductility) and **S** (seismic) variants for better deformation capacity and seismic performance.
4. **Fe 550 / Fe 550D**: 550 MPa yield strength with **D** (enhanced ductile) option for heavy structures requiring both high strength and ductility.
5. **Fe 600**: Highest common grade at 600 MPa; used where maximum strength and space efficiency are critical (e.g., high-rise buildings, bridges). **Designation Format**: Fe 500D: "Fe" = steel, "500" = yield MPa, "D" = enhanced ductility.

1.2 HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL (IS-2062 (2011)): A Detailed Overview

1.2.1 Introduction & Scope

IS 2062:2011 specifies requirements for **structural steels**—plates, strips, bars, flats and rolled sections (angles, tees, beams, channels, I-sections)—used in welded, bolted or riveted assemblies and general engineering. It ensures that steels supplied for buildings, bridges, industrial structures and heavy equipment meet consistent standards of chemical composition, mechanical performance, dimensional accuracy and surface quality. By covering everything from micro-alloyed plates to deformed bars, IS 2062 underpins safe, durable, cost-effective construction across diverse infrastructure projects.

1.2.2 Key Features of IS 2062 Steel

1. **Wide Scope of Products**: Covers structural steel plates, strips, flats, bars and rolled sections (angles, tees, beams, channels, I-sections) for welded, bolted or riveted construction.
2. **Nine Yield-Based Grades**: Classified E 250 through E 650 by minimum yield strength, with sub-qualities (A, BR, B0, C) defining impact-test levels and de-oxidation method.
3. **Supply & Manufacture Controls**: Steel may be ingot- or continuously-cast, semi-killed or killed, with agreed rolling routes (as-rolled, controlled rolling, normalizing) to achieve targeted mechanical properties.
4. **Freedom from Defects**: Mandates clean rolling, free of laminations, cracks or harmful flaws; allows only minimal, controlled grinding or weld repairs under strict thickness limits.
5. **Marking & Traceability**: Each product bears manufacturer's name/trade-mark, grade designation, cast/heat number and color-coded ends to ensure full traceability.

1.2.3 Advantages Using of IS 2062 Steel

1. **Consistency & Reliability**: Tight chemical and mechanical criteria guarantee uniform performance batch-to-batch.
2. **Guaranteed Weldability**: Defined CE limits and de-oxidation practices ensure sound welds without post-weld embrittlement.
3. **Design Efficiency**: High-grade options (E 550–E 650) permit lighter sections, reducing steel tonnage and foundation loads.
4. **Enhanced Toughness**: Sub-qualities B0/C provide verified impact resistance at low or sub-zero temperatures—ideal for cold or seismic regions.
5. **Low Rejection & Re-test Rates**: Clear defect-removal and re-test clauses minimize on-site rejections, keeping projects on schedule.

1.2.4 Typical Application IS 2062 Steel

- **Building & Bridge Construction**: Beams, columns, trusses and girders in high-rise buildings, flyovers and overpasses.
- **Industrial & Process Plants**: Structural frames, storage tanks, pressure vessels and pipe racks in refineries, petrochemical and power plants.
- **Heavy-Duty Components**: Crane rails, excavator booms, track shoes and foundation piles.
- **Infrastructure Projects**: Metro viaducts, airport hangars, dockyard cranes and offshore platform modules.
- **General Engineering**
  Machine bases, supports, fabrications and welded assemblies across automotive, rail and heavy-equipment industries.

1.2.5 Grades & Designation IS 2062 Steel

- Grade Classification: Steel is categorized based on minimum yield strength into nine grades: E 250, E 275, E 300, E 350, E 410, E 450, E 550, E 600, and E 650 (where "E" denotes yield strength in MPa).
- Sub-qualities:
  - E 250 to E 410 include four sub-qualities: A, BR, B0, and C
  - E 450 to E 650 include: A and BR only
- Designation Format: Follows the format "E <yield strength> <quality>", e.g. E 250C, E 500BR
- Impact Test Requirements:
  - A: No impact test, semi-killed/killed steel
  - BR: Optional impact test at room temperature
  - B0: Impact test at 0°C, mandatory
  - C: Impact test at –20°C, mandatory

Refer: Clause 5, Table 1 & 2 | IS 2062:2011

Table 1 Chemical Composition
(*Clauses* 5, 8.1 *and* 8.2)

Grade Designation	Quality	Ladle Analysis, Percent, *Max*					Carbon Equivalent (CE), *Max*	Mode of Deoxidation
		C	Mn	S	P	Si		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
E 250	A	0.23	1.50	0.045	0.045	0.40	0.42	Semi-killed/killed
	BR B0	0.22	1.50	0.045	0.045	0.40	0.41	Semi-killed/killed
	C	0.20	1.50	0.040	0.040	0.40	0.39	Killed

1.2.6 Chemical Composition & Micro-alloying

- Micro-Alloying Allowed: Up to 0.25% total of niobium (Nb), vanadium (V), titanium (Ti). These improve strength-to-weight ratio, grain refinement, and toughness.
- Carbon Equivalent (CE) Limits:
    - ≤ 0.42% for fully killed steel
    - ≤ 0.53% for semi-killed steel
      Ensures excellent weldability (Clause 3.2).

Strict Impurity Control:

- Sulphur (S) & Phosphorus (P) ≤ 0.045%
- Nitrogen (N) ≤ 0.012% (Clause 8.1, Note 9) Optional Alloying: Elements like Cr, Ni, Cu can be added for corrosion resistance or toughness on mutual agreement (Clause 8.1, Notes 6 & 7).

Refer: Clause 8, Table 1 | IS 2062:2011

Table 2 Mechanical Properties
(*Clauses* 5, 10.3, 10.3.1, 11.3.1, 12.2 *and* 12.4)

Grade Designation	Quality	Tensile Strength R_m, *Min* MPa[1)] (*See* Note 1)	Yield Stress R_{eH}, *Min* MPa[1)]			Percentage Elongation A, *Min* at Gauge Length, L_o=5.65	Internal Bend Diameter *Min* (*See* Note 2)		Charpy Impact Test (*See* Note 3)	
			<20	20-40	>40		≤ 25	>25	Temp °C	*Min* J
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
E 250	A	410	250	240	230	23	2t	3t	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27

1.3 Measurement Uncertainty and its Significance

In any physical testing or calibration activity, the result of a measurement is never absolutely exact. There always exists a degree of doubt or variability surrounding the measured value, which is scientifically referred to as **Measurement Uncertainty (MU)**. According to the **International Vocabulary of Metrology (VIM)** and as stated in **NABL 141** (General Guidelines for Estimation of Uncertainty in Measurement), Measurement Uncertainty is:

"A non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used."

In simpler terms, MU provides a **quantitative estimate of the quality and reliability of a measurement**, allowing users to judge how much confidence can be placed in the reported value.

Uncertainty of measurement is thus an expression of the fact that, for a given measurand and a given result of measurement of it, there is not one value but an infinite number of values dispersed about the result that are consistent with all the observations and data and one's knowledge of the physical world and that with varying degrees of creditability can be attributed to the measurand.

The uncertainty of result of measurement reflects the inexact knowledge of the value of measurand. The word measurement should be understood to mean both a process and the output of that process. In general, a measurement has imperfections that give rise to error in the measurement result. Traditionally an error is viewed as having two components, namely a random component and a systematic component.

Random errors arise from unpredictable and spatial variation of influence quantities, which affect the outcome of a measurement process. **These may include:**

- The way measurement method is employed,
- The variation in environment conditions in the laboratory,
- Inherent instability of measuring equipment,
- Personal judgment of test engineer / analyst

Furthermore, measurement uncertainty serves as a critical indicator for instrument calibration needs. Over time, measuring instruments can drift from their original accuracy. By monitoring measurement uncertainty, engineers can determine when instruments require recalibration to maintain data reliability and integrity. This ensures that measurements continue to reflect the true values of the quantities being measured. In the context of scientific research, for example, consistent and reliable measurements are paramount to drawing valid conclusions from experiments. Measurement uncertainty helps researchers assess the trustworthiness of their data and identify potential areas where instrument calibration might be necessary.

Beyond these specific applications, measurement uncertainty is a foundational tool for process improvement. By systematically identifying and addressing the sources of uncertainty, engineers can significantly enhance process robustness, reliability, and compliance. Imagine a manufacturing process that relies on a temperature measurement to control a chemical reaction. Various factors, such as sensor limitations or environmental fluctuations, can contribute to uncertainty in the temperature measurement. By understanding these uncertainties, engineers can implement corrective actions, such as using higher-precision sensors or improving temperature control within the reaction vessel. This proactive approach to managing uncertainty leads to more robust processes, where the desired outcome is consistently achieved within the specified parameters.

In essence, measurement uncertainty empowers process engineers to refine their craft, minimize errors, and deliver superior results. By acknowledging the inherent variability in measurements and taking steps to mitigate it, engineers can achieve a new level of precision and control in industrial processes.no

1.3.1 Why Measurement Uncertainty is Evaluated?

Evaluation of MU is essential in all fields of testing and calibration for several reasons (NABL 141, Section 3.2.9 and your notes):

1. **Indicates Quality of Measurement**: It provides a numerical indication of the confidence level or quality of the reported value.
2. **Allows Comparisons**: Measurement results from different sources or laboratories can only be compared **meaningfully** when their uncertainty is known.
3. **Supports Method Validation**: Helps identify **major sources of error** (e.g., in mass, yield load, rib area), guiding refinement in sampling and calibration.
4. **Improves Measurement Systems**: By understanding and reducing sources of uncertainty, **procedures and instruments** can be improved.
5. **Ensures Result Validity**: Accurate estimation of uncertainty allows confidence in declaring **pass/fail criteria**, especially when values are close to specification limits (e.g., yield stress in IS 2062 steel).

1.3.2 Types of Measurement Uncertainty

Measurement uncertainty comprises in general many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components which may be evaluated by Type B evaluation of measurement uncertainty can also be characterized by standard deviations, evaluated from probability density functions based on experience or further information.

- Type A Evaluation of Measurement / Uncertainty Type A Evaluation: Evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions.
- Type B evaluation of measurement / Uncertainty Type B evaluation: Evaluation of a component of measurement uncertainty determined by means other than a Type A evaluation of measurement uncertainty
- Combined Standard Uncertainty: Total uncertainty from all sources (Type A and Type B), combined mathematically. It shows how much doubt exists in the final measured value.
- Expanded Uncertainty: Expanded uncertainty is the range around your measured value that you're 95% confident the true value lies within. It is calculated by multiplying the combined uncertainty U_c with a coverage factor k, which is usually 2 for 95% confidence.

CHAPTER 2: LITERATURE REVIEW

2.1 Uncertainty in Measurement of Nominal Mass, Yield Strength, Tensile Strength and Rib Area of IS 1786: 2008 and IS 2062: 2011

1. **Nominal Mass (W/L)**

Definition: Nominal mass is determined by dividing the measured weight (W) by the measured length (L) of the steel bar.

Uncertainty Sources:

- Type A: Repeatability in measuring length and diameter using vernier callipers or rulers introduces variation due to alignment or manual reading error.
- Type B: Calibration uncertainty of the electronic balance used to measure mass. This includes resolution, drift, and calibration certificate accuracy.

Even a small deviation in length or balance reading can significantly affect calculated nominal mass per meter, which is critical for compliance with IS 1786 tolerance limits.

2. **Tensile Strength & Yield Stress (UTS & YS)**

Definition: These are mechanical properties determined during tensile testing using a Universal Testing Machine (UTM).

Uncertainty Sources:

- Type A: Variability in cross-sectional area (calculated using measured diameter), and gauge length setting repeatability during testing.
- Type B: Accuracy of the UTM load cell, calibration traceability, and alignment of the specimen.

Any misalignment in gripping, deviation in cross-section measurement, or load-cell nonlinearity can influence stress values and result in false acceptance/rejection of material.

3. **Stress Ratio (UTS/YS)**

Definition: This is the ratio of ultimate tensile strength to yield strength, used to evaluate ductility and strain hardening.

Uncertainty Sources:

- It is a derived quantity, so its uncertainty depends on the combined uncertainties of both UTS and YS.
- Propagated using uncertainty propagation formulas, considering correlation between the two measurements.

Accurate stress ratio is vital in classifying ductility levels in HSD bars, especially in seismic zones as per IS 1786.

4. **Rib Area Measurement (IS 1786: 2008)** Definition: Rib area is related to the surface deformations (ribs) that ensure bond strength with concrete.

Uncertainty Sources:

- Type A: Variation in rib height, rib spacing, and bar diameter measurements taken using profile projectors or micrometres.
- Type B: Instrument calibration, twist pitch variation in rolled bars, and surface irregularities.

Errors in rib area measurement can affect bond strength estimation and lead to incorrect compliance decisions for bar types (Fe 500D, etc.).

2.2 NABL Document 141: Guidelines for the Estimation and Expression of Uncertainty in Measurement

Detailed guidelines on the estimate and expression of measurement uncertainty are given in NABL (National Accreditation Board for Testing and Calibration Laboratories) document 141.It is, therefore, common in almost all NABL-accredited laboratories. This guideline provides a systematic procedure to help users identify and quantify sources of uncertainty in measurement.

Key Reasons for Measurement Variability.

1. **Instrument Limitations and Calibration Issues**: Measuring instruments may suffer from calibration drift, limited resolution, zero error, or response time lag. Even well-calibrated equipment has some inherent uncertainty, and discrepancies may arise if used outside its optimal range or without proper recalibration.
2. **Variations in Measurement Method**: The procedure used—such as test speed, alignment, or sample preparation—can significantly impact results. Inconsistencies in applying the method, especially in destructive tests like tensile or bend tests, introduce variability that affects the reliability of the outcome.
3. **Operator Skill and Human Judgment**: Different operators may interpret readings differently, apply varying levels of force, or inconsistently align samples. Human judgment—especially in tasks like visual inspection, reading analog scales, or recording measurements—can introduce subjective errors.
4. **Environmental and Surrounding Conditions**: External factors like temperature, humidity, vibrations, or even lighting can alter instrument behaviour and sample properties. For example, metal expands with heat—so uncontrolled temperature during a dimensional test can skew results.
5. **Sample or Material Inconsistencies**: Variability within the sample itself—such as surface roughness, microstructure, or rib height in steel—can lead to measurement differences even under controlled conditions. This is particularly true in heterogeneous or irregular materials like reinforced steel or composites.

2.3 Quantifying Measurement Uncertainty

Quantifying measurement uncertainty involves a systematic process of identifying all significant sources of variability and estimating their contributions to the final measurement result. The goal is to provide a **numerical expression of confidence** in the measured value, typically in the form:

Measured Value ±U (with a defined confidence level)

where **U** is the expanded uncertainty calculated from the combined standard uncertainty. MU quantification involves the statistical modelling of test data for the establishment of a confidence interval around the measured values. This should include the following processes:

- **Repeatability tests**: Several test carried out under precisely same conditions to show the repeatability of results.
- **Reproducibility tests**: Tests done at different times with different operators, equipment, etc., to demonstrate the robustness of the measurement process.

2.4 Defining Parameters

Here are the brief explanations and formula related to the specific terms from the NABL 141 document:

1. Repeatability: Closeness of agreement b/w the results of successive measurements of same measurand carried out under repeatability conditions.

The repeatability conditions are:

- same measurement procedure.
- same observer.
- same measuring instrument, used under same conditions.
- same locations.
- repetition over a short period.

2. Reproducibility: Closeness of agreement b/w the results of the measurement of same measurand carried out under changed conditions of measurement.

A valid statement of reproducibility requires specification of conditions changes includes:

- Principal of measurement
- method of measurement
- observer
- measuring instrument
- reference standard
- location
- time & condition of use.

3.True Value: Value that is perfectly consistent with the definitions of given specific quantity.

4. Measurement: **S**et of operations having the objective of determining a value of a quantity.

5. Bias: Diff. b/w measurement result and accepted reference value. Bias is the total systematic error. **Example**: Suppose a scale consistently shows a weight 0.5 kg higher than the actual weight due to incorrect calibration — this 0.5 kg is the **bias**.

6. **Accuracy:** It shows how close a measured value (or values) is to the true or accepted reference value.

- Estimation: Sometimes represented a: ***Accuracy≈ max |X−Xi|***

where:

- X = reference or true value
- Xi = individual measurement values

Note: *Accuracy is influenced by both systematic errors (bias) and random errors (precision).*

Example: If the true length is 100 cm and your measurements are 98, 100, and 102 cm, the maximum deviation from the true value is 2 cm, which indicates accuracy.

7.Precision: It indicates the **consistency or repeatability** of measurements when repeated under the same conditions.

- Estimation: Often measured as the **maximum deviation from the mean** of the readings:

Precision≈ max |Xi−X¯|

where:

- Xi = individual readings
- X¯ = mean of all readings

Note: Precision does **not** indicate how close the measurements are to the true value — only how **close they are to each other**.

Example: If your measurements are 50.1, 50.2, and 50.0 mm (all close to each other), you have high **precision**, even if the true value is 52 mm.

8. **Error:** The error is the diff. b/w TRUE value, X, and a MEASURED value- ***Error=Xi−X***

Types: Errors can be divided into:

- **Systematic Error** (Bias): consistent and repeatable (e.g., faulty calibration)
- **Random Error**: varies unpredictably between measurements (e.g., due to environmental noise)

9. **Random Error**: The **Random Error** is the difference between a **single measurement result** and the **true mean value** (which would be obtained if you took an infinite number of measurements under the same repeatable conditions).

- Mathematically: ***Random Error=*** $\mathrm{X_i} - \mathrm{X}_{\infty}^{-}$

where:

- X_i = individual measurement
- X_{∞}^{-} = mean of infinite repeated measurements (under same conditions)

Cause: Random errors are caused by unpredictable variations — e.g., environmental changes, human reaction time, slight fluctuations in instrument performance.

Example: If you weigh a 1.00 kg object multiple times and get:
0.98 kg, 1.01 kg, 0.99 kg, the variation in these results is due to **random error**.

10.**Systematic Error**: The **Systematic Error** is the part of total error that **remains even after averaging** out the random errors. It's usually **constant or predictable** and **shifts all measurements in the same direction**.

- **Formula**: *Systematic* ***Error=Total Error−Random Error*** x

Cause: Poor instrument calibration, misreading scale consistently, environmental bias (e.g., temperature), etc.

Example: If all your weights are consistently 0.2 kg higher than the true value, it's a **systematic error**, likely due to incorrect scale calibration.

11. **Standard Deviation:** The standard deviation is a measure of the dispersion or variability of a set of values. It is the positive square root of the variance. For a sample of n observations $x_1,\ x_2, \dots\dots, x_n$, the standard deviation 's' is calculated as:

$$s = \sqrt{\left(\frac{1}{n-1} * \sum_{i=1}^{n}(x_i - \bar{x})^2\right)}$$, where $\bar{x}$ is the sample mean.

12.**Varience:** A measure of dispersion, which is the sum of the squared deviations of observations from their average divided by one less that the no. of observations.

$$\text{Variance} = \mathrm{s}^2$$

13. **Sensitivity Coefficient:** It describe how the output estimate y varies with changes in the input estimates $x_1, x_2, \ldots\ldots, x_{n.}$ They are the partial derivatives of the function f that relates the estimates to the output:

$$c_i = \frac{\partial f}{\partial x_i}$$

These coefficients are used to translate the uncertainty in input quantities into the uncertainty in output quantity.

14. **Uncertainty:** Uncertainty is a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand. It is evaluated using both Type A (statistical analysis) and Type B (other means) methods.

15. **Combined:** The combined standard uncertainty $u_c(y)$ is the positive square root of the combined variance, which is calculated by combining the standard uncertainties of the input estimates:

$$u_c^2(y) = \sum_{i=1}^{N} (\frac{\partial f}{\partial x_i})^2 u_c^2(x_i)$$

16. **Effective Degree of Freedom:** The effective degree of freedom v_{eff} for the combined standard uncertainty is approximated using **Welch-Satterthwaite** formula:

$$v_{eff} = \frac{(u_c^2(y))^2}{\sum_{i=1}^{N} (\frac{u^4(x_i)}{v_i})}$$

Where v_i are the degree of freedom associated with each standard uncertainty component.

Why it matters

- You need ν_{eff} to pick the right coverage factor k (from the Student's t-distribution) for your desired confidence level.
- Lower ν_{eff} → "fatter" tails on t → larger k.

The effective degrees of freedom let you translate from a combined standard uncertainty to a confidence interval via the t-distribution.

17. **Coverage Factor** *k*: The coverage factor *k* is used to expand the combined standard uncertainty to obtain an interval that encompasses a large fraction of the distribution of values. The expanded uncertainty ***U*** is given by:

$$U = ku_c(y)$$

The value of k is chosen based on the desired confidence level and is typically in the range of 2 to 3. The choice of *k* depends on the distribution of the measured and the desired confidence level. Common values are 1, 2, and 3 for 68.27%, 95.45% and 99.73% confidence levels, respectively.

18. **Confidence Level:** The confidence level refers to the probability that the interval defined by the expanded uncertainty encompasses the true value of the measurement. It is denoted as *p,* and a higher confidence level corresponds to larger coverage factor.

19. **Expanded Uncertainty:** Expanded uncertainty ***U*** provides an interval around the measurement result that may be expected to encompass a large fraction of the values that could be attributed to the measurand. It is calculated by multiplying the combined standard uncertainty by coverage factor:

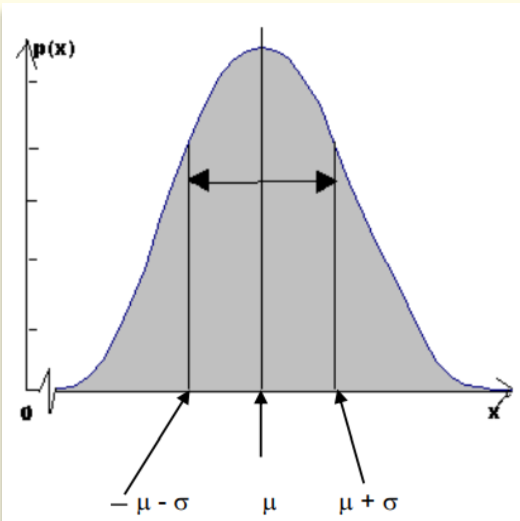
$$U = ku_c(y)$$

The measurement result is then expressed as y±U.

These concepts and formulae are essential for understanding and expressing the uncertainty in measurement according to the guidelines provided by NABL.

20. **Probability distribution:** The probability density function p(x) of the normal distribution is as follows:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-(x-\mu)^2 / 2\sigma^2\right] \qquad -\infty < x < +\infty$$



In measurement science, the **normal distribution** is employed whenever there is no compelling evidence to suggest a different underlying error model. This choice rests on two fundamental justifications:

1. **Central Limit Theorem (CLT):** In practical measurements, the total error often arises from the sum of many small, independent effects (e.g., slight variations in instrument response, ambient conditions, operator judgment). By the CLT, the aggregate of these influences tends toward a normal distribution, regardless of each individual source's distribution.

2. **Repeatability Studies:** When we perform a series of identical measurements under unchanged conditions, the scatter of those results almost invariably conforms to a bell-shaped curve. Assuming normality allows we to characterize repeatability with a single parameter—the standard deviation—and to apply well-established coverage factors (e.g., k = 2 for ~95 % confidence) without bias.

By adopting a normal-distribution model, we align with international guidelines (e.g., GUM, NABL 141), ensure analytical simplicity, and maintain traceability and comparability across laboratories. Because this assumption is both theoretically sound and empirically validated, it stands up to rigorous peer review and audit.

In practice, we model repeatability and overall measurement uncertainty with a normal distribution because:

1. **Aggregate of Many Small Errors:** Every measurement is influenced by numerous tiny, independent effects—instrumental noise, ambient fluctuations, operator positioning, etc. The Central Limit Theorem tells us that when you sum such independent contributions, their combined distribution converges to a Gaussian form, even if each individual effect is non-Gaussian.

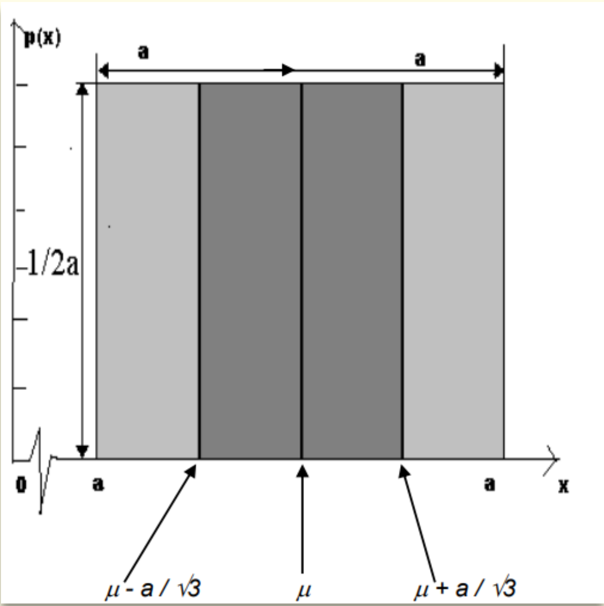
2. **Empirical Validation:** When identical measurements are repeated under stable conditions, the scatter almost invariably traces out a bell-shaped histogram. Treating it as normal lets us summarize repeatability entirely by its standard deviation, simplifying both analysis and communication.

3. **Standards and Traceability:** International frameworks (GUM, NABL 141) explicitly recommend assuming normality in the absence of contrary evidence, so that coverage factors ($k \approx 2$ for ~95 % confidence) remain consistent, transparent, and auditable across laboratories.

By grounding our uncertainty calculations in a normal-distribution model, we ensure both theoretical rigor and practical defensibility.

21.**Rectangular Distribution:** The probability density function p(x) of rectangular distribution is as follows:

$$P(x) = \frac{1}{2a}, a_- < x < a_+ , \textit{where } a = (a_+ - a_-)/2$$



When to use Rectangular Distribution?

Use of a **rectangular (uniform) distribution** is appropriate whenever you know only the **bounds** of an uncertainty source—its minimum and maximum possible values—but have no reason to favour any value within that interval. In practice, this applies directly to:

- **Instrument Least Count:** A measuring device can neither resolve nor indicate finer increments than its least count. Any true value lies somewhere within ±½ least-count of the displayed reading, and without further insight, all positions in that interval are equally plausible.

- **Manufacturer's Accuracy Specifications:** When a device's accuracy is quoted as $\pm\Delta$, it means the error will not exceed Δ but could be anywhere between $-\Delta$ and $+\Delta$. In the absence of bias information, treating this error as uniformly distributed ensures a conservative, non-assumptive model.

By adopting a rectangular distribution for these bounded uncertainties, you adhere to GUM recommendations, maintain computational simplicity, and avoid introducing unjustified bias—ensuring a transparent, defensible uncertainty budget.

2.5 IS 1786: 2008 High Strength Deformed Steel Bars and Wires for Concrete Reinforcement

IS 1786 is the Indian Standard that specifies requirements for **high-strength deformed steel bars and wires** for concrete reinforcement. These bars are widely used in reinforced concrete structures due to their high yield strength and ductility. The standard includes both regular grades and "D" variants (D for enhanced ductility) to ensure suitability for seismic and dynamic loading conditions.

Mechanical Properties:

- **Grades and Yield Strength:** IS 1786 covers grades **Fe 415, Fe 500, Fe 550, and Fe 600**, where the number indicates the minimum yield stress in MPa. For example, **Fe 500** has a minimum yield strength of 500 MPa.

- **Ultimate Tensile Strength (UTS):** The UTS must be at least 1.08 times the yield strength. For Fe 500, this translates to a minimum UTS of 545 MPa.

- **Elongation:** The percentage elongation varies by grade and ductility class. Ductile grades (like Fe 500D) offer higher elongation (≥16%) to accommodate better energy absorption during seismic events.

- **Bond Strength:** Deformed bars under IS 1786 are designed with ribs to provide superior bond strength with concrete, enhancing load transfer and structural stability.

- **Bend and Re-bend Properties:** Bars must pass standard bend and rebend tests without cracking, ensuring durability under site conditions and fabrication stresses.

Advantages:

1. **High Yield Strength:** Allows for reduced bar sizes and steel quantity, optimizing cost and structural weight.

2. **Improved Ductility:** D and SD variants offer higher ductility, making them ideal for earthquake-prone zones.

3. **Excellent Bonding with Concrete:** Ribbed profile enhances grip with concrete, minimizing slippage.
4. **Corrosion Resistance (Optional Coatings):** Can be supplied with epoxy or other corrosion-resistant coatings when required.
5. **Reliable Weldability:** Controlled carbon equivalent ensures good weldability for site joints.

Applications:

- **Reinforced Cement Concrete (RCC) Structures:**
  Widely used in beams, slabs, columns, and foundations of residential, commercial, and industrial buildings.
- **Bridges and Flyovers:**
  Essential for tension members and deck slabs subjected to dynamic loads.
- **Seismic-Resistant Structures:**
  Fe 500D and Fe 550D are preferred for earthquake-prone regions due to better ductility.
- **High-Rise Buildings:**
  Used for vertical and lateral load resistance with optimized reinforcement.
- **Precast Concrete Elements:**
  Ideal for factory-produced beams, panels, and blocks due to consistent strength.
- **Infrastructure Projects:**
  Employed in highways, tunnels, metros, and irrigation channels needing high reinforcement integrity.

2.6 IS 2062:2011 – Hot Rolled Medium and High Tensile Structural Steel

Overview:

IS 2062 is an Indian Standard that specifies the technical requirements for hot-rolled medium and high tensile structural steel. It is widely used in structural and mechanical engineering applications. The steel under this standard is suitable for welding, machining, and forming, making it versatile for a wide range of load-bearing and fabricated structures.

Mechanical Properties:

- **Yield Strength:**
  IS 2062 steel is available in multiple grades – E250, E275, E300, E350, E410, and E450 – where the numeric value indicates the minimum yield strength in MPa. For example, E250 has a yield strength of 250 MPa.
- **Tensile Strength:**
  Each grade ensures a minimum tensile strength, e.g., 410–540 MPa for E250 grade. Higher grades possess increased strength and slightly reduced ductility.

- **Elongation:**
  Lower grades such as E250 generally provide higher elongation (around 23%), which improves ductility and formability.
- **Impact Strength:**
  Higher quality levels (especially Quality C) are tested for impact resistance at sub-zero temperatures (e.g., -20°C), which ensures toughness in cold or dynamic loading conditions.
- **Weldability:**
  IS 2062 steel has excellent weldability due to controlled carbon content and low levels of impurities, making it ideal for structural joints.

Advantages:

1. **Good Weldability:**
   Suitable for welding without the need for preheating or post-weld heat treatment for most applications.
2. **Excellent Machinability and Formability:**
   Ideal for cutting, shaping, and forming, especially in automated manufacturing.
3. **High Strength-to-Weight Ratio:**
   Offers strength needed for heavy-duty structures without excessive weight.
4. **Impact Resistance:**
   Performs well under fluctuating or impact loads due to good toughness.
5. **Availability in Multiple Grades:**
   Wide range of strength levels available depending on application needs (E250 to E450).

Applications:

- **Bridges and Flyovers:**
  Used in girders, beams, and trusses requiring high strength and fatigue resistance.
- **Industrial and Power Plant Structures:**
  Frameworks, boiler supports, and towers use IS 2062 steel for reliability and durability.
- **Shipbuilding and Marine Structures:**
  Used in non-corrosive treated form for hull and structural parts.
- **Heavy Machinery:**
  Applied in the construction of cranes, earthmovers, and trailers.
- **Automobile Chassis and Frames:**
  Employed in automotive manufacturing where strength and formability are critical.
- **Storage Tanks and Pipelines:**
  Utilized due to ease of welding and leak-proof joints.
- **Railway Coaches and Wagons:**
  Suitable for underframes and other high-load parts due to high yield strength.

CHAPTER 3: METHODOLOGY

3.1 IS 1786: 2008 HIGH STRENGTH DEFORMED STEEL BARS AND WIRES FOR CONCRETE REINFORCEMENT – SPECIFICATION (FOURTH REVISION)

3.1.1 Scope of IS 1786 (as per Clause 1): The standard applies to **deformed steel bars and wires** used in concrete reinforcement. It covers the following grades:

a) **Fe 415, Fe 415D**
b) **Fe 500, Fe 500D**
c) **Fe 550, Fe 550D**
d) **Fe 600**

"Fe" indicates the **minimum 0.2% proof/yield stress in N/mm²**.The **"D" variant** indicates **same strength but higher minimum elongation** for improved ductility.

3.1.2 Test Specimens: Specimens should be representative of the batch in a standardized manner. Dimensions should be measured to calculate Nominal Mass, Cross Sectional Area and Gauge Length. For checking nominal mass, mechanical properties, bend test and re-bend test, test specimen of sufficient length shall be cut from each size of the finished bar/wire at random at a frequency not less than that specified in Clause 11 of IS 1786: 2008.

1. Surface must be sound and free from pipes or harmful defects; all bars must have longitudinal and transverse ribs per code. **Bar Sizes Tested:** 8 mm, 10 mm, 12 mm, 16 mm, etc.
2. **Sampling Guidelines** (as per IS 1786 Clause 6 & 7):
   I. Sample length: Minimum of 1 m for nominal mass; longer for tensile tests (as per gauge length).
   II. Ensure bar ends are cleanly cut without deformation.

3.1.3 Determination of Nominal Mass and Cross-Sectional Area: Clause 6 & 7

Procedure:

1. Measure the length(l) of the specimen using measuring tape in (mm).
2. Weight(w) the specimen to the nearest gram with a weighing balance.
3. Calculate Cross-Sectional Area (CSA) in (mm^2) = $\frac{\mathbf{w}}{\mathbf{0.00785 \times l}}$ $-(\boldsymbol{cl-6.3.1})$
4. Compute Nominal Mass = $\mathbf{0.00785} \times (\boldsymbol{CSA})$ $-(\mathbf{cl-7.2.1})$
5. Check for the tolerance and range of the Nominal mass in the clause 6.2 Table 1 and Table 2

Note- For Bars of uniform cross-section

Table 1 Nominal Cross-Sectional Area and Mass
(*Clause* 6.2)

Sl No.	Nominal Size mm	Cross-Sectional Area mm^2	Mass per Metre kg
(1)	(2)	(3)	(4)
i)	4	12.6	0.099
ii)	5	19.6	0.154
iii)	6	28.3	0.222
iv)	8	50.3	0.395
v)	10	78.6	0.617
vi)	12	113.1	0.888
vii)	16	201.2	1.58
viii)	20	314.3	2.47
ix)	25	491.1	3.85
x)	28	615.8	4.83
xi)	32	804.6	6.31
xii)	36	1 018.3	7.99
xiii)	40	1 257.2	9.86

Table 2 Tolerances on Nominal Mass
(*Clauses* 6.2 *and* 7.2.2)

Sl No.	Nominal Size mm	Tolerance on the Nominal Mass, Percent		
		Batch	Individual Sample[1]	Individual Sample for Coils Only[2]
(1)	(2)	(3)	(4)	(5)
i)	Up to and including 10	±7	–8	±8
ii)	Over 10 up to and including 16	±5	–6	±6
iii)	Over 16	±3	–4	±4

[1] For individual sample plus tolerance is not specified. A single sample taken from a batch as defined in **3.1** shall not be considered as individual sample.
[2] For coils batch tolerance is not specified.

3.1.4. Gauge Length (GL) Determination (Clause 10.2.1)

Initial Gauge Length $(L_o) \rightarrow L_o = 5.65 \times \sqrt{CSA} \quad (IS\ 1608\ (Part - 1)\ CL - 8.1)$

where, $CSA\ in\ mm^2$ & $L_o\ in\ mm$

Procedure:

I. Compute for each HSD bar based on its measured CSA.
II. Mark gauge length (Lo) on the specimen surface - Punching on Testing sample (centred on the reduced section for tensile testing).
III. Take half of gauge length on vernier and choose one end of the sample mark first 2 point on sample.
IV. Then take length = GL on vernier and then start marking on sample with respect to the first 2 point which was marked on the sample. In this way GL will be more accurately marked and error will be less.
V. Mark both ends of **Lo** using **fine scribe, line, or punch**—must not cause **premature fracture**.
VI. Accuracy of marking: ±1%.
VII. Lo can be rounded to nearest 5 mm if within **10%** of calculated Lo.
VIII. For longer test pieces, use overlapping gauge lengths if needed.
IX. A line along axis can help align gauge markings.

Note: GL to be round-off to nearest integer and then punched.

Make sure that length of the sample should be sufficient such that at least 6 points shall be marked on sample.

Fig.2: *Source-Mechanical Lab at BIS*

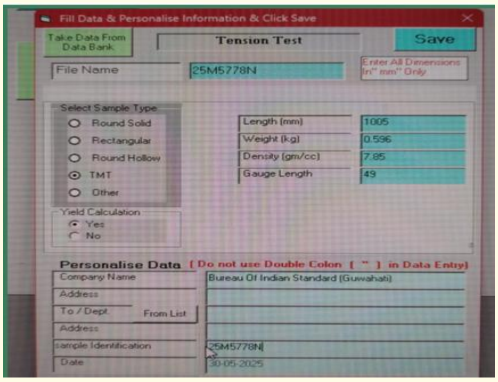
Figure on the left shows HSD bars on which Gauge Length being marked and punched with the help of punch.

3.1.5. Tensile & Yield Strength Testing (Clause 9.2)

Determine Yield stress (YS), Tensile stress (TS), and Percentage elongation of HSD bars

Tensile Testing procedure:

1) Data Entry in Computer: Input initial data like Sample ID, Length(mm), Weight (kg), Density, Initial Gauge length.



2) Specimen Mounting: Secure the prepared specimen between the UTM grips, ensuring proper alignment along the loading axis.

   i) **Test pieces must be gripped using suitable devices** such as wedge grips, screw grips, parallel jaws, or shouldered holders, ensuring the **tensile force is applied axially** to avoid bending, which can affect results—especially for brittle materials or when determining yield/proof strength.

   ii) A **preliminary aligning force** (not exceeding **5% of the expected yield strength**) may be applied before testing; if used, **extension correction** must be made to exclude any deformation caused by this initial force.

3) Machine setup: Ensure safety shields are in place and the machine is ready for testing.

   (1) **The force-measuring system must be zeroed after assembling the loading setup but before gripping the test piece**, so that the system excludes the weight of the grips and any clamping effects from the measurement.

   (2) **Once set, the zero point must remain unchanged throughout the test**, ensuring that only the **actual tensile force** applied to the specimen is recorded accurately.

4) Loading Process: The machine applies load gradually until the specimen fractures.

5) Post-Fracture Measurements: Remove the broken specimen and measure the final gauge length using vernier or extensometer

6) Final data entry: Input the final gauge length into the computer to calculate elongation % and complete the test report.

3.1.6. Data Collection and Calculation

I. Calculate Nominal Mass (Linear Density) = $\frac{M}{L}$ (in Kg/m)

II. Measured Cross-Sectional Area and Gauge Length.

III. Calculation of Yield Stress $R_P = \frac{F_{YIELD}}{CSA}$ (in MPa)

IV. Calculation of Tensile Strength $R_M = \frac{F_{ULTIMATE}}{CSA}$ (in MPa)

V. Determine Stress Ratio $= \frac{R_M}{R_P}$

VI. Calculate Percentage Elongation at Fracture $\in = \frac{\Delta L}{L_o} \times 100\%$ **, where** $\Delta L = L_f - L_o$

- $L_f \rightarrow$ Gauge Length after Fracture
- $L_o \rightarrow$ Initial Gauge Length

3.1.7. Verification of Result and Tolerance Check

The **measured mechanical properties** (e.g. yield strength, tensile strength, elongation) must be **verified against the specified values** in IS 1786: 2008 Cl 9.2 and Table 3 as shown below:

Table 3 Mechanical Properties of High Strength Deformed Bars and Wires
(*Clause* 8.1)

Sl No.	Property	Fe 415	Fe 415D	Fe 415S	Fe 500	Fe 500D	Fe 500S	Fe 550	Fe 550D	Fe 600	Fe 650	Fe 700
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
i)	0.2 percent proof stress/ yield stress, *Min*, N/mm^2	415.0	415.0	415.0	500.0	500.0	500.0	550.0	550.0	600.0	650.0	700.0
ii)	0.2 percent proof stress/ yield stress, *Max*, N/mm^2	–	–	540.0	–	–	650.0	–	–	–	–	–
iii)	TS/YS ratio [1], N/mm^2	≥ 1.10 (butTS not less than 485 N/mm^2)	≥ 1.12 (but TS not less than 500 N/mm^2)	≥ 1.25	≥ 1.08 (but TS not less than 545 N/mm^2)	≥ 1.10 (but TS not less than 565 N/mm^2)	≥ 1.25	≥ 1.06 (but TS not less than 585 N/mm^2)	≥ 1.08 (but TS not less than 600 N/mm^2)	≥ 1.06 (but TS not less than 660 N/mm^2)	≥ 1.06 (but TS not less than 700 N/mm^2)	≥ 1.06 (but TS not less than 770 N/mm^2)
iv)	Elongation, percent, *Min*, on gauge length $5.65\sqrt{A}$, where *A* is the cross-sectional area of the test piece	14.5	18.0	18.0	12.0	16.0	16.0	10.0	14.5	10.0	10.0	10.0
v)	Total elongation at maximum force, percent, minimum on gauge length $5.65\sqrt{A}$, where *A* is the cross-sectional area of the test piece (*see* 3.0) [2]	–	5	8	–	5	8	–	5	–	–	–

[1] TS/YS ratio refers to ratio of tensile strength to the actual Yield strength or 0.2 percent of yield stress of the test piece.
[2] Test, wherever specified by the purchaser.

3.1.8. Universal Testing Machine – UTN-(E)-40 (UTM-40)

The UTM-40 is a 400 kN (40 tonne) electromechanical universal testing machine designed for high-precision tensile, compressive and bending tests on metals, polymers, composites and other engineering materials. Its semi-automatic operation, digital control and extensometer support enable accurate, repeatable measurements that comply with international test standards.

Major Components

- **Upper Cross-Head**: Houses the primary load cell and upper grip or compression platen. Provides rigid support for the applied force.
- **Movable Cross-Head**: Precisely driven by a ball-screw actuator under motor control. Adjusts test space and applies uniform load to the specimen.
- **Tensile & Compression Zones**
    - **Tensile Zone:** Up to 1 000 mm clear span for standard dog-bone or sheet specimens.
    - **Compression Zone:** Below the lower platen, with removable support blocks for cubes and cylinders.
- **Base & Table**: Welded steel frame for minimal deflection. Integrated work surface for specimen preparation and fixture storage.
- **Load Indicator & Control Panel**: Real-time digital readout of force (kN/N), programmable set-points, peak-hold and emergency-stop. Intuitive keypad or touchscreen UI for test parameters.

4. Working Principle

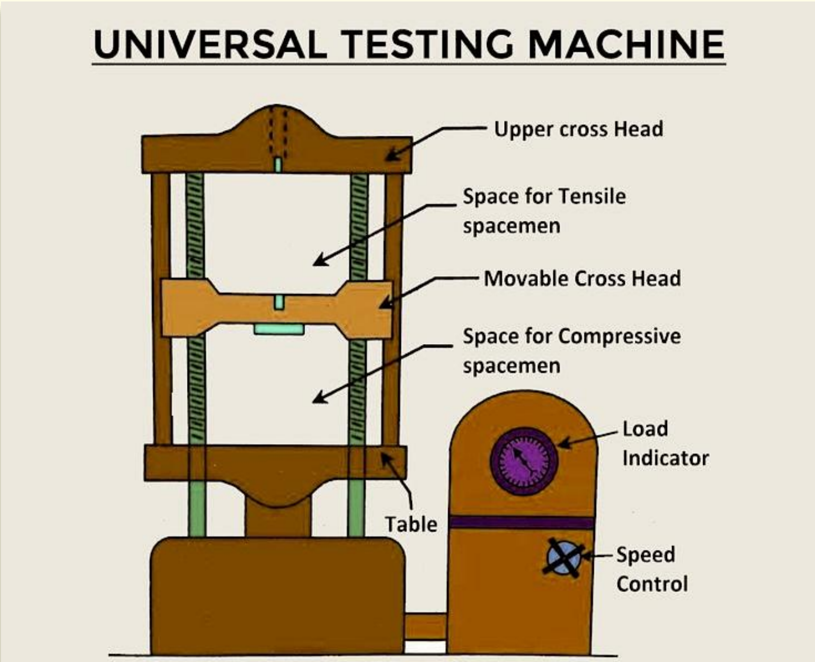
1. **Hydraulic/Electromechanical Drive**: A servomotor (or hydraulic pump) pressurizes fluid that moves the piston assembly. In electromechanical versions, a ball-screw actuator converts motor torque into axial motion.
2. **Load Application**: The piston transmits a steadily increasing tensile or compressive force to the specimen via grips or platens. The machine ensures uniform load distribution to mimic real-world stress conditions.
3. **Force Measurement**: A high-precision load cell—calibrated to better than 0.4 % MU—converts the mechanical force into an electrical signal. The digital indicator displays and logs this force with 20 N resolution and 1 % reading accuracy.
4. **Strain Measurement (Optional)**: An extensometer clamps onto the specimen and records axial elongation or compression. These signals feed into the digital controller or PC software, enhancing strain accuracy for modulus, yield and elongation determinations.
5. **Data Acquisition & Reporting**: Throughout the test, force vs. displacement data are captured in real time. Upon completion, results (e.g., ultimate tensile strength, yield strength, elongation at break, compressive strength, bending load) can be exported directly to USB or processed via dedicated PC software for stress–strain curves and test certificates.

5. Typical Test Workflow

1. **Fixture Selection:** Choose tensile grips, compression platens or bending fixtures; install in the cross-heads.

2. **Zeroing & Setup:** Tare the load cell and extensometer; set cross-head speed and target set-points in the control panel.
3. **Specimen Mounting:** Secure the test specimen between grips or on platens. Confirm alignment.
4. **Execution:** Initiate the test. The machine ramps load at the programmed rate, monitoring force and displacement continuously.
5. **Completion & Analysis:** On reaching failure or set limit, the machine stops automatically. Review, print or export test data and generate required reports.

Note: *All values (MU, least count, accuracy) are factory-declared; periodic calibration against certified standards is recommended to maintain traceability and compliance.*



Determines the ultimate tensile strength, yield strength, compressive strength and bending strength of metals and alloys in MPa (Mega. Pascal).

For tensile and yield strength, the test piece is fixed between the jaws and pulled till the breaking point.

The load at which the test piece breaks is noted and the tensile strength of the material is calculated.

Based on the strength of the material under test, the load value goes up to 360 kN (kilo Newton).

Products tested: Various types of metal products like rods, bars, flats, structural items etc.

Parameter	Value
Capacity	400 kN
Declared Measurement Uncertainty (MU)	0.372 %
Uncertainty Factor (K)	2
Least Count	20 N
Accuracy	1 % of reading
Cross-Head Speed Range	0.5–500 mm/min
Data Interfaces	USB, RS-232, PC-based software

Fig.: UTM(E)-40

All the information provided in the table are referenced from the calibration certificate of UTM(E)-40.

Source-Mechanical Lab BIS GBL.

Attribute	Details
Instrument	Digimatic External Micrometre
Declared Measurement Uncertainty	0.0014
Identification	BISL/EQP/154
Measuring Range	0 – 25 mm
Least Count (Resolution)	0.001 mm
Manufacturer (Make)	Mitutoyo
Accuracy	0.002

- Resolution of 0.001 mm enables detection of tiny thickness variations (<0.01 mm), whereas a typical vernier calliper resolution (~0.02 mm) may overlook subtle differences critical in high-precision tests.
- Ratchet-stop mechanism applies a consistent measuring force, reducing operator-induced variability common with calliper measurements.
- Fine-pitch spindle thread reduces backlash, ensures smooth movement and provides higher mechanical advantage, yielding highly reproducible readings with minimal random error.
- Hardened measuring faces minimize wear over time, maintaining accuracy when measuring thin specimens.
- Narrow anvil contacts allow precise placement on small or uneven surfaces, unlike broader calliper jaws.

Attribute	Details
Instrument	Baker IP67 Digital Vernier Caliper
Measuring Range	0-150mm
Least Count (Resolution)	0.01 mm
Measuring Faces	Hardened stainless steel jaws
Declared MU (k = 2, 95 %)	0.008 mm
Accuracy	0.02

- **Versatile measurement:** external, internal and depth dimensions in one tool, reducing the need for multiple gauges.
- **Broad 0–150 mm range:** accommodates most lab specimens, though samples larger than 150 mm require alternative instruments.
- **0.01 mm digital resolution:** speeds data collection, but may miss ultra-fine changes below ~0.005 mm.
- **Instant display:** minimizes reading errors, yet accuracy depends on consistent thumb pressure and jaw alignment.
- **Rugged design:** IP67-sealed slider and hardened jaws resist wear, though rack-and-pinion backlash can arise without routine maintenance.

The measuring tape is a 2 m roll-up with 0.001 mm graduations, calibrated to ISO 7500-1 standards. Declared measurement uncertainty is 0.00028 m at coverage factor K = 2 (95 % confidence). Calibration against gauge blocks traceable to national length standards ensures traceability. The uncertainty budget includes Type B contributions from certificate tolerance, graduation nonlinearity, thermal expansion, and reading error; Type A repeatability effects were negligible under laboratory conditions. This tape is employed for linear measurements—specimen length, gauge-mark positioning, and rib spacing—with all values reported alongside uncertainty.

The precision centre punch employed for specimen marking is manufactured from AISI 6150 chrome–vanadium steel, hardened to HRC 58–62. It features a 90° conical tip with a nominal diameter of 6 mm and a knurled grip to ensure controlled force application. Designed to produce crisp, repeatable indentations on steel bar surfaces, this punch facilitates accurate alignment for subsequent measurements. Its robust construction and optimal hardness minimize tip wear and deformation, guaranteeing reliable performance throughout testing without the need for formal calibration procedures.

The V-shaped anvil used for specimen support is machined from AISI 1045 medium-carbon steel, quenched and tempered to HRC 28–32 for enhanced wear resistance. Its upper face features a 60° V-groove, 10 mm deep and 5 mm wide at the apex, precisely ground to ensure secure positioning of round and ribbed bars. The rigid mass and toughness of the anvil absorb punch impact, preventing lateral movement and deformation of the sample. No formal calibration is required, as the anvil serves solely as a stable, repeatable support fixture during punching operations.

Attribute	Details
Instrument	Digital Balance
Declared Measurement Uncertainty	0.008
Identification	BISL/EQP/04
Measuring Range	40 gm to 15 Kg
Least Count (Resolution)	0.002 Kg
Manufacturer (Make)	Essae-DIGI
Accuracy	0.004

The digital balance used for mass measurements features a capacity range of 40 g to 15 kg with dual-readability: 0.01 g for loads up to 2 kg and 0.1 g for 2 kg–15 kg. It incorporates an internal calibration routine traceable to national mass standards and is housed within a draft-shield enclosure to minimize air-current effects. Declared repeatability is ±0.02 g (low-range) and ±0.2 g (high-range), with linearity within ±0.05 g. The uncertainty budget considers Type B contributions from calibration certificate tolerance, resolution limits, and environmental influences (temperature, vibration), while Type A repeatability under controlled laboratory conditions was found negligible. All specimen masses are reported with these well-defined uncertainties.

3.1.8. Mean Rib Area Calculation (Cl: 5.2-5.6)

Mean Projected Rib Area per Unit Length ($\boldsymbol{A_r}$), Cl 5.4 Formula for transverse Ribs:

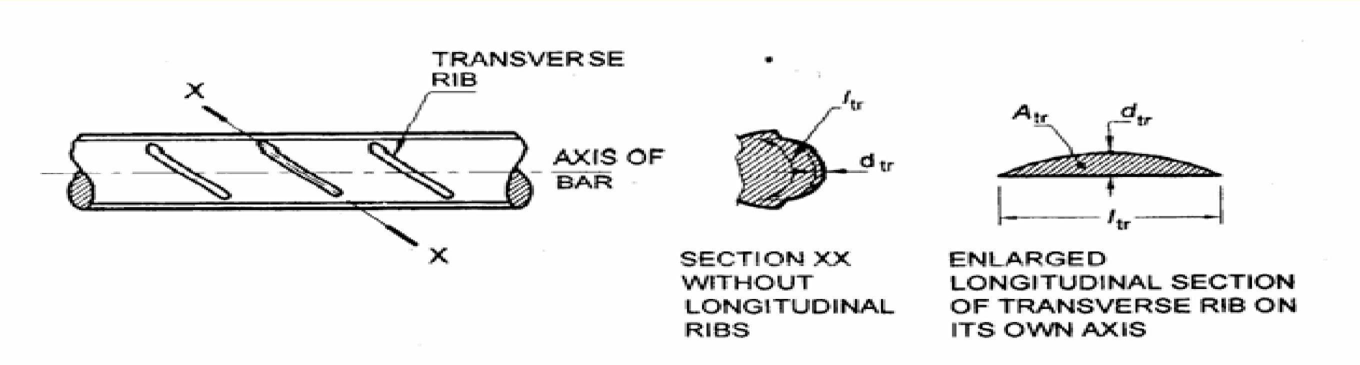
$$\boldsymbol{A_r} = \sum_{i=1}^{n_t} \frac{A_{ti}.\sin\theta}{S_t} \quad \text{, where } \boldsymbol{A_{ti}} = \frac{2}{3} \times \boldsymbol{l_{tr}} \times \boldsymbol{d_{tr}} \text{ (in } mm^2\text{)}$$

- $\boldsymbol{A_{ti}}$ = longitudinal sectional area of i[th] transverse rib
- $\boldsymbol{\theta}$ = inclination of rib to bar axis (°)
- $\boldsymbol{S_t}$ = transverse rib spacing (mm)
- $\boldsymbol{n_{tr}}, \boldsymbol{l_{tr}}$ = number and height of longitudinal ribs
- $\emptyset$ = nominal diameter (mm) of HSD Bar

Rib Height & Spacing (Clause 5.5 & 5.6) Transverse Rib Height: Measured at centre of 10 successive ribs. Spacing (S): Measured over 10 gaps between ribs →$\boldsymbol{S_t} = \frac{\boldsymbol{Measured\ Length}}{\boldsymbol{No.of\ Spaces}}$

Deformation Limits for Bond Strength (Clause 5.2) Minimum projected rib area per unit length:

- $A_r = \begin{cases} \mathbf{0.12} \times \emptyset\ (for\ \emptyset\ \leq 10\ mm) \\ \mathbf{0.15} \times \emptyset\ (for\ 10\ mm < \emptyset\ \leq 16\ mm) \\ \mathbf{0.17} \times \emptyset\ (for\ \emptyset\ > 16\ mm) \end{cases}$



*NOTE—$\boldsymbol{A_{tr}}, \boldsymbol{d_{tr}}$ **and** $\boldsymbol{l_{tr}}$ represent longitudinal sectional area, height and length respectively of transverse Rib*

Fig: - Determination of Longitudinal Sectional Area $\mathbf{A_{tr}}$ of a transverse Rib

Procedure:

1. Take imprints of the rod rib pattern on the A4 sheet using.
2. Now mark 2 faces A and B for 2 faces of rod. Take imprints such that 2 faces can be differentiated easily.
3. Now measure the Rib angle, Length, Height, S_{tr}. Note: For Str length should be taken such that it should be: $\geq \mathbf{10} \times \emptyset\ (\boldsymbol{in\ mm})$
4. Now calculate the area using the formula for diff. ribs and find its sum:
   a. $\boldsymbol{A_r} = \sum \boldsymbol{A_i},\ (where\ i\ is\ no.of type\ of\ Rib)$
5. Ensure that sum should satisfy the condition as mentioned. Take multiple readings of each parameter to get accurate results and to measure Uncertainty.

Rib Area Calculation (Parabola approximation)

The parabola formula assumes that the rib height, as function of distance along the circumference of the rebar, can be approximated by a second order curve.

Due to assumed symmetry only one quarter of the geometry needs to be solved ,and subsequently multiplied by 4 (2 rib rows with 2 symmetrical half ribs per row).

- If we denote the distance along the circumference by symbol **s**, and rib height as **y(s)**, then we need to solve for the coefficient **b** in the general eqn. of **parabola**.
- $y(s) = -b.s^2 + a_m$,*where* a_m *is the rib height at* $s = 0$ (1)
- This is easily done by substituting value of zero rib height at $\rightarrow s = \frac{\pi.d}{4}$

$$0 = -b.(\frac{\pi.d}{4})^2 + a_m \quad \rightarrow \quad y = -a_m.(\frac{4}{\pi.d})^2.s^2 + a_m \qquad (from\ (1))$$

We denote Total Projected Rib Area by$\rightarrow A_{ti}$

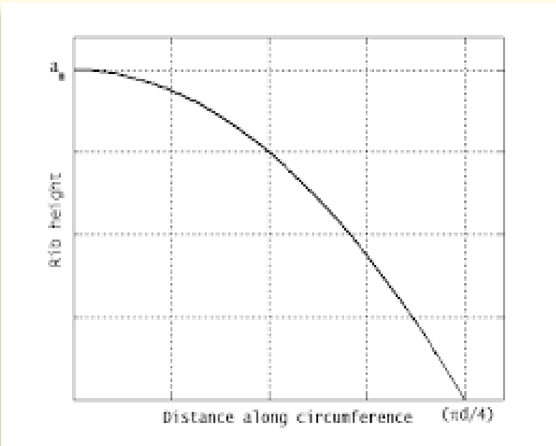
$$\frac{A_{ti}}{4} = \int_0^{\frac{\pi.d}{4}} a_m.\left(1 - \left(\frac{4}{\pi.d}\right)^2.s^2\right)ds \Rightarrow A_{ti} = 4.a_m \int_0^{\frac{\pi.d}{4}} \left(1 - \left(\frac{4}{\pi.d}\right)^2.s^2\right)ds$$

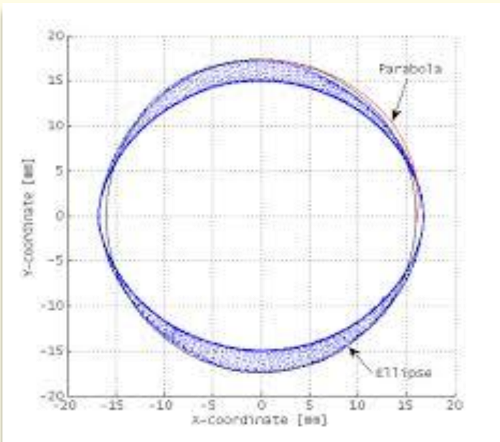
$$\Rightarrow A_{ti} = 4.a_m.\left[s - \frac{1}{3}.\left(\frac{4}{\pi.d}\right)^2.s^3\right]_0^{\frac{\pi.d}{4}}$$

$$\Rightarrow A_{ti} = 4.a_m.\left(\frac{\pi.d}{4} - \frac{1}{3}.\frac{\pi.d}{4}\right)$$

$$\Rightarrow A_{ti} = \frac{2}{3}.a_m.(\pi.d)$$

$\Rightarrow \frac{A_{ti}}{2} = \frac{2}{3}.d_{tr}.(l_{tr})$ $as\ l_{tr} = \frac{\pi.d}{2}$ This represents the area of one half of RIB





In the first figure X-axis represent Distance along circumference and Y-axis tells Rib Height.

(Parabolic Shape of rib height) (***Source*** :Technical Paper by JP Jordan)

Rib-imprint profiles were captured by placing a sheet of carbon paper between the reinforcement bar and a clean white backing sheet, then applying uniform pressure along the bar's length to transfer the rib geometry. The resulting high-contrast imprint faithfully reproduces each rib's crest and furrow, enabling precise measurement of rib length, spacing, and helix angle. Measurements were performed using a digital calliper (least count 0.01 mm) for linear dimensions and a protractor attachment for angular assessment. This non-destructive technique ensures clear delineation of rib contours, facilitates repeatable data acquisition under consistent contact pressure, and provides traceable inputs for subsequent uncertainty analysis of rib area and bond-performance characteristics.

Rib Area Calculation

$Face - A$

$\theta_{avg.} = 71^o$ $\quad d_{tr,avg.} = 1.262mm$

$l_{travg} = 26.11mm$

$S_{tr,avg} = \frac{169}{19} mm$ $\quad A_1 = \frac{2}{3} \times \frac{l_{tr} \times d_{tr} \times \sin(\theta)}{S_{tr}}$ $\quad \Rightarrow A_1 = 2.33513mm^2$

$Face - B$

$\theta_{avg.} = 68.833^o$ $\quad d_{tr,avg.} = 1.172mm$

$l_{travg} = 26.366mm$

$S_{tr,avg} = \frac{171}{19} mm$ $\quad A_2 = \frac{2}{3} \times \frac{l_{tr} \times d_{tr} \times \sin(\theta)}{S_{tr}}$ $\quad \Rightarrow A_2 = 2.13457mm^2$

Total Area=4.46965 mm^2> 0.15∗Ø=2.4 mm^2

3.1.9. General Information regarding testing rates (IS 1608: Part 1Cl 10.3)

Unless otherwise agreed, the choice of method (A1, A2, or B) and test rates are at the discretion of the producer or the test laboratory assigned by the producer, provided that these meet the requirements of IS 1608: Part 1.

NOTE 1: The difference between Method A and Method B is that the necessary testing speed of Method A is defined at the point of interest (e.g. Rp0,2), where the property has to be determined, whereas, in Method B, the necessary testing speed is set in the elastic range before the property (e.g. Rp0,2) has to be determined. Under certain conditions using Method B (e.g. for some steels a stress rate in the elastic range of approximately 30 MPa/s, using a testing rig and clamping system with high stiffness and a test piece geometry according to Annex B, Table B.1 IS 1608 Part-1, Test piece type 2), a strain rate near the range 2 of Method A may be observed.

NOTE 2: Product standards and corresponding test standards (e.g. aerospace standards) can specify test rates that are different from those contained in this document.

Method A: Strain-Rate Controlled (Clause 10.3.2)

1. **Objective:** Minimise variation of strain rate exactly when determining strain-sensitive parameters (e.g. upper yield strength Re, proof strengths Rp and Rt) and reduce measurement uncertainty.

Strain-Rate Control (Method A) – As per Clause 10.3.2 of IS Standard

Method A ensures consistent strain application during tensile testing to reduce measurement errors, particularly in determining yield strength and elongation.

Types of Method A:

- A1 (Closed-Loop):
  Utilizes real-time feedback from an extensometer to control the actual strain rate by adjusting the crosshead speed dynamically.
- A2 (Open-Loop):
  Uses a fixed crosshead speed to estimate the strain rate over the parallel length without feedback.

Formula:

$$\boldsymbol{eL = \frac{V_c}{L_C}}$$

Where:

- Vc = Crosshead separation speed (mm/s)
- Lc = Parallel length of the specimen (mm)
- e˙L = Estimated strain rate over the parallel length (s^{-1})

When to Use Each Method:

- For materials with continuous yielding, both A1 and A2 give comparable results.
- For materials with discontinuous or serrated yielding (common in high-strength steel), Method A2 (Open-Loop) is preferred for better control and stability.

Method B: Stress-Rate Controlled (Clause 10.3.3.1)

1. **Objective:** Impose a target stress-rate in the elastic region by fixing crosshead speed, without closed-loop control.
2. **Procedure:**
    - Any convenient crosshead speed may be used until the specimen reaches half the specified yield strength.
    - Above half-yield stress, set the crosshead speed to achieve the required stress-rate (see Table 3 of the standard).
3. **Notes & Limitations:**
    - Not intended to maintain true constant stress-rate through yield—machine compliance and serrated yielding can cause stress-rate to drop or even reverse.
    - Simpler to implement but less precise for strain-sensitive measurements.

3.2 IS 2062: 2011 HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL — SPECIFICATION (Seventh Revision)- Method of testing

3.2.1. Scope of IS 2062 (Clause 6.1-6.3)

1. **Grades & Sub-qualities:**
    - Nine grades of structural steel: E 250, E 300, E 350, E 410, E 450, E 500, E 550, E 600, E 650.
    - Grades E 250–E 410 have four sub-qualities (A, BR, B0, C); grades E 450–E 650 have two (A, BR).
    - Sub-qualities denote impact-test requirement and de-oxidation:
        - **A:** no impact test, semi-killed/killed
        - **BR:** impact optional at 25 °C, semi-killed/killed
        - **B0:** impact mandatory at 0 °C, semi-killed/killed
        - **C:** impact mandatory at –20 °C, killed
2. **Manufacturing & Casting:**
    - Steelmaking, casting (ingot or continuous), and hot-rolling process left to supplier's discretion.
    - Secondary refining (ladle treatment, vacuum degassing) and final rolling condition (as-rolled, normalized, controlled rolling, accelerated cooling) by purchaser-supplier agreement.
3. **Material Source:**
    - Only virgin steel directly from steel-making is acceptable.
    - Re-rolled scrap or material with undocumented metallurgical history is **not** permitted.

3.2.2. Freedom from Defects (Clause 7.1-7.2.1)

1. **Surface Quality:**
    - Finished steel must be **well-rolled**, clean, and conform to specified dimensions/sections.
    - Must be reasonably free of surface flaws, laminations, jagged or imperfect edges, and other harmful defects.
2. **Defect Removal by Grinding:**
    - Minor surface defects may be ground off, provided **local thickness reduction ≤ 4 %**.
    - Grinding that reduces thickness by > 4 % but ≤ 7 % allowed only with purchaser's agreement.
3. **Defect Repair by Welding:**
    - With purchaser's consent, defects beyond grinding scope may be chipped or ground, **repaired by welding**, and inspected per a mutually agreed procedure.

3.2.3. Selection and Preparation of Test Samples (Clause 9.1-9.9)

1) **Location for Sampling:** Samples shall be taken from positions (see Fig. 1) that best represent both **longitudinal and transverse properties** of the product. For plates > 12 mm from HR coil, tensile specimens **must** be cut in the **transverse direction** to capture through-thickness variations.

2) **Retention of Rolled Surface:** Wherever practicable, retain the **original rolled surface** on two opposite faces of the specimen to preserve true surface condition. For flats/plates ≤ 32 mm, both rolled faces remain; for > 32 mm, at least **one** rolled face must remain. Round specimens only if thickness > 20 mm.

3) **Minimum Machining:** Flats up to 16 mm thick and bars < 28 mm diameter must be tested **without machining**. Bars 28–71 mm may be **symmetrically machined**; > 71 mm, take samples from designated zones as shown in Figure. Machining is kept to the **minimum** to avoid altering the material's properties.

4) **Bend Test Specimens:** Rectangular bend specimens should, as far as possible, be of the **full product thickness**. For thickness > 28 mm, removal of metal from one side is permitted; ensure the **rolled face** is on the **outer** side during bending.

5) **Traceability & Handling:** Before cutting, the manufacturer must supply **cast number, size and mass** of all products in the cast (and number of plates). Cutting by shearing or flame shall leave extra material for finishing; deformation must be minimized. No heat treatment unless the parent material is simultaneously treated; any straightening must be done **cold**.

Why Specific Positions?

- Taking samples from prescribed positions ensures that the test pieces reflect the **true mechanical behaviour** in both rolling (longitudinal) and across-rolling (transverse) directions, capturing potential variations due to rolling, cooling, or section-dependent microstructure.

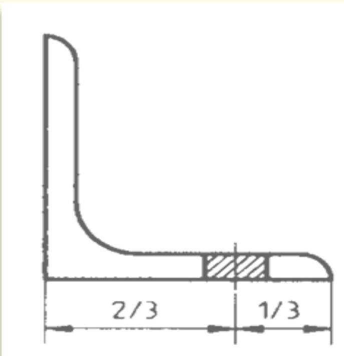


Fig a

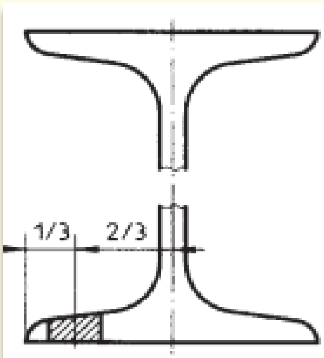


Fig b

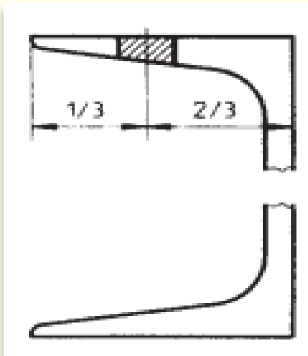


Fig c

Figure: (Source IS 2062 CL 9)

Specimens for tensile testing of rolled structural sections are taken from critical locations to reflect true material behaviour (IS 2062, Fig. 1). For I-section beams, a full-depth slice including flange and web is removed at the one-third flange width position to capture differing microstructures. Similarly, C-sections yield specimens cut through the web just inside the flange at the same 1/3–2/3 division. Angle-section samples are extracted parallel to the rolling direction, incorporating both legs. This ensures representative properties from regions affected by rolling, cooling, and section geometry.

Per IS 2062/ISO 6892-1, plate or bar samples are machined into a "dumb-bell" (dog-bone) shape so that the narrow central gauge section (length Lo, width b_0) concentrates deformation and fracture there, while the wider ends fit gripping jaws without inducing bending. You first rough-cut the outline, then machine accurate transition radii into the shoulders and finish the parallel gauge length. During the tensile test, all elongation and failure occur in this uniform reduced section, giving reliable mechanical properties.

3.2.4. Nominal Mass Measurement

1) **Dimensional Measurement:** Measure **width, thickness, and diameter** (as applicable) at **five equidistant points** along each bar or section. Record all values to calculate the **average dimensions** for use in cross-sectional area calculation.
2) **Physical Mass Measurement:** Use a **calibrated electronic balance** (resolution ±0.1 g) to measure the **mass (W)** of each sample. Measure the **length (L)** using a **steel tape** with millimetre accuracy.
3) **Nominal Mass Calculation (W/L):**

   Compute **linear mass density** as: $\boldsymbol{m} = \frac{\boldsymbol{M}}{\boldsymbol{L}}\ (\boldsymbol{in}\frac{\boldsymbol{Kg}}{\boldsymbol{m}})$
4) **Cross-Sectional Area (CSA):**

   From the average dimensions, compute:

$$\boldsymbol{CSA} = \left\{ \left(\frac{\pi . d^2}{4}\right), \text{for round bars ofdiameter} = \mathrm{d(inmm)} \right.$$
$$= \{ \mathrm{w} \times \mathrm{t}, \text{for rectangular section of width} = \text{'w' and thickness} = \text{'t'}$$

Verify that Cross-Sectional Area$\approx \frac{\mathrm{m}}{\rho}$ where $\rho = 7850\ \mathrm{Kg/m^3}$

3.2.5. Gauge Length (GL) Determination (Clause 10.2.1)

Initial Gauge Length $(\boldsymbol{L_o}) \rightarrow \boldsymbol{L_o} = \boldsymbol{5.65} \times \sqrt{\boldsymbol{CSA}} \quad (\boldsymbol{IS\ 1608\ (Part - 1)\ CL - 8.1})$

where, $\boldsymbol{CSA\ in\ mm^2}$ & $\boldsymbol{L_o\ in\ mm}$

Procedure:

I. Compute for each sample based on its measured CSA.
II. Mark gauge length (Lo) on the specimen surface - Punching on Testing sample (centred on the reduced section for tensile testing).
III. Take half of gauge length on vernier and choose one end of the sample mark first 2 point on sample.
IV. Then take length = GL on vernier and then start marking on sample with respect to the first 2 point which was marked on the sample. In this way GL will be more accurately marked and error will be less.
V. Mark both ends of **Lo** using **fine scribe, line, or punch**—must not cause **premature fracture**.
VI. Accuracy of marking: ±1%.
VII. Lo can be rounded to nearest 5 mm if within **10%** of calculated Lo.
VIII. A line along axis can help align gauge markings.

Note: GL to be round-off to nearest integer and then punched.

3.2.6. Introduction to Test-Piece Standardization

1. Introduction to Test-Piece Standardization

Mechanical testing of metals (tensile tests, in particular) demands not only precise instrumentation but also highly controlled specimen geometries. By prescribing the shape, dimensions, tolerances, and preparation methods of "test pieces," standards such as IS 1608 (Part 1): 2022 (which adopts ISO 6892-1:2019 norms) eliminate—or at least minimize—variability arising from specimen manufacture. This ensures that measured properties (yield strength, ultimate tensile strength, elongation at fracture, etc.) truly reflect material behaviour, rather than artifacts of specimen shape or surface condition.

2. Thin-Product Test Pieces (Annex B: 0.1–3 mm thickness)

1. **Geometry and Grip Design**
   - **Wider grip ends** taper smoothly (radius ≥ 20 mm) into the parallel gauge section. This prevents stress-concentrations and slippage in grips, especially critical for materials that can buckle or wrinkle under clamp pressure.
   - **Parallel-sided variants** (no enlarged ends) are permitted by agreement for very narrow strips (≤ 20 mm), allowing testing of actual product widths without machining away the edges.
2. **Dimensioning & Tolerances**
   - Three non-proportional specimen types (Table B.1) cover a range of widths (12.5, 20, 25 mm) and gauge lengths. Specimens thinner than 0.5 mm call for extra care: any edge work-hardening from shearing must be removed by machining.
   - **Width tolerances** (e.g. ± 0.05 mm for 12.5 mm nominal width) let you calculate cross-sectional area from the nominal value—so you don't have to micrometre every specimen, yet still keep area uncertainty below 2 %.
3. **Surface & Cutting Methods**
   - As-rolled surfaces should, if possible, remain intact to preserve realistic material texture and hardness.
   - Punch-cut specimens in highly work-hardening alloys can show artificially elevated yield strengths; hence, milling or precision grinding is recommended for such grades.
   - For very thin foils (< 0.5 mm), strips are cut, bundled with paper separators, then milled to final dimensions—avoiding burrs and localized damage.
4. **Area Measurement Accuracy**
   - Maximum total error in original cross-sectional area (So) must not exceed ± 2 % (width error ≤ ± 0.2 %). For higher-precision work, aim for ± 1 % or better by using specialized thickness gauges and micrometres.

Table B.1 — Dimensions of test pieces

Dimensions in millimetres

Test piece type	Width b_o	Original gauge length L_o	Parallel length L_c		Free length between the grips for parallel sided test piece
			Minimum	Recommended	
1	12,5 ± 1	50	57	75	87,5
2	20 ± 1	80	90	120	140
3	25 ± 1	50[a]	60[a]	—	Not defined

[a] The ratio L_o/b_o and L_c/b_o of a type 3 test piece in comparison to one of types 1 and 2 is very low. As a result, the properties, especially the elongation after fracture (absolute value and scatter range), measured with this test piece, will be different from the other test piece types.

3. Thicker-Product Test Pieces (Annex D: ≥ 3 mm sheets/flats & ≥ 4 mm bars)

1. **Shape & Transition Radii**
   - **Cylindrical specimens** (do ≥ 3 mm) use a transition radius ≥ 0.75 do; flat specimens use ≥ 12 mm. These generous fillets eliminate crack-initiation sites at the grip-to-gauge junction.
   - Cross-sections can be circular, square, rectangular (width/thickness ≤ 8:1), or special profiles—matching the real component geometry when required.
2. **Proportional vs. Non-Proportional Specimens**
   - **Proportional specimens** tie the gauge length (Lo) to cross-sectional area via Lo = k·√So (k = 5.65 or 11.3). This scaling ensures that, across varied diameters, necking and strain-distribution are comparable—critical for evaluating ductility.
   - **Non-proportional specimens** (fixed L_o, b_o combinations given in Table D.2) may be used if a product-specific standard prescribes them.
3. **Dimensional Tolerances**
   - Machining tolerances (e.g. ± 0.02–0.03 mm on diameters up to 18 mm) permit using nominal dimensions directly in stress calculations. Shape tolerances (max deviation along gauge length, e.g. 0.03–0.05 mm) further constrain area uncertainty.
   - If tolerances aren't met, each specimen's cross-section must be measured individually.
4. **Specimen Preparation & Surface Condition**
   - Machining from billets or bars should avoid overheating; coolant and low-cutting speeds preserve the annealed surface layer.
   - Unmachined sections (structural bars, wires) can be tested "as-received" if product standards allow. In such cases, careful alignment and true axial loading are essential to avoid bending stresses.

Table D.1 — Circular cross-section test pieces

Coefficient of proportionality k	Diameter d mm	Original gauge length $L_o = k\sqrt{S_o}$ mm	Minimum parallel length L_c mm
5,65	20	100	110
	14	70	77
	10	50	55
	5	25	28

Table D.2 — Typical flat test piece dimensions

Dimensions in millimetres

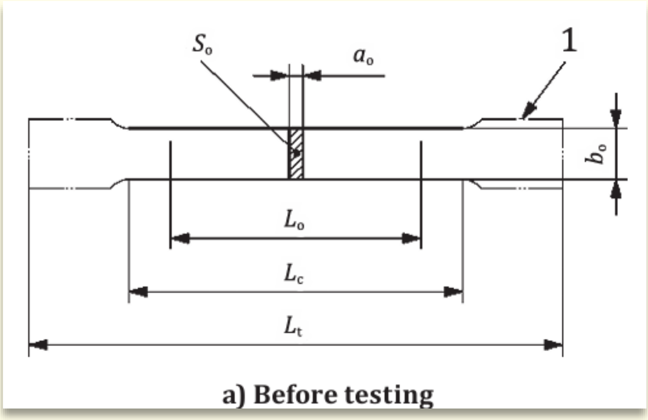
Width b_o	Original gauge length L_o	Minimum parallel length L_c	Approximately total length L_t
40 ± 0,7	200	220	450
25 ± 0,7	200	212,5	450
20 ± 0,5	80	90	300

4. Key Benefits for Testing Laboratories

- **Reproducibility**: Different labs using identical specimen geometries can compare results directly.
- **Traceability**: Deviations from specified tolerances are documented, aiding in uncertainty budgets.
- **Product-Standard Alignment**: Manufacturers and end-users rely on uniform testing procedures for acceptance, quality control, and certification.
- **Accurate Mechanical Characterization**: Proper specimen design eliminates grip-induced failures and measurement artifacts—delivering trustworthy data for design, simulation, and failure analysis.

5. Conclusion

Adhering rigorously to the Annex B and D test-piece specifications of IS 1608 (Part 1): 2022 / ISO 6892-1: 2019 underpins the integrity of all tensile test results. By controlling geometry, machining tolerances, and surface condition, one ensures that the intrinsic mechanical properties of metallic materials are measured accurately—forming a sound basis for engineering design and material selection.



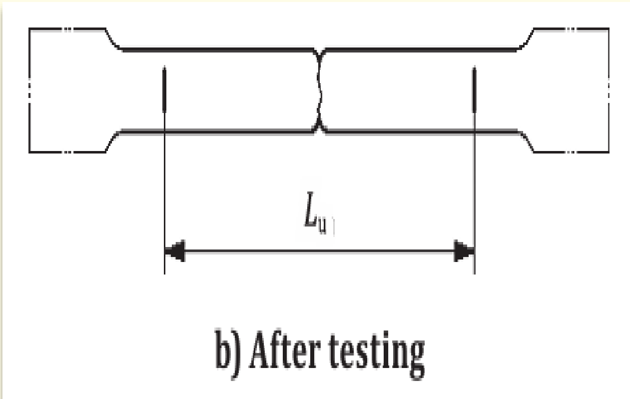


Figure: Source IS 1608 - Machined test pieces of rectangular cross-section

Key:

- **a_o** - original thickness of a flat test piece or wall thickness of a tube
- **b_o** - original width of the parallel length of a flat test piece
- **L_c** - parallel length
- **L_o** - original gauge length
- **L_t** - total length of test piece
- **L_u** - final gauge length after fracture
- **S_o** - original cross-sectional area of the parallel length
- 1 gripped ends

NOTE: The shape of the test-piece heads is only given as a guide

Give below in figure from Fig. a to Fig. c shows how gauge length is marked and punched on machined sample of IS 2062.

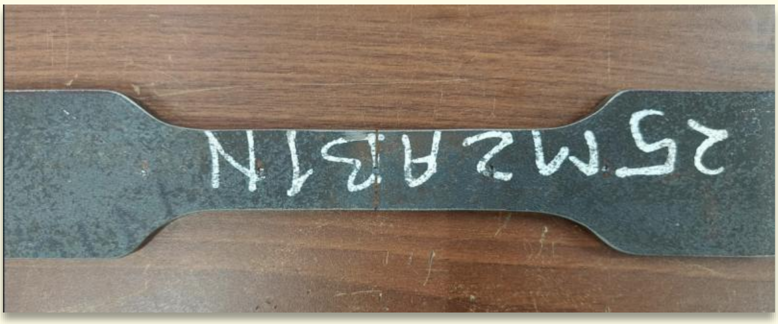


Fig. a: *Source Lab- Sample cut from the Structural Steel*

Fig. b: *Source Lab- Gauge length marking on the sample*

Fig. c: *Source Lab- Punching on the sample before testing*

Fig. :On right shows how to fix in b/w the jaws of the UTM (Upper head and lower head) Makes sure that gap between upper head and lower head is less than GL and it is hold in b/w so that it does not break at edge.

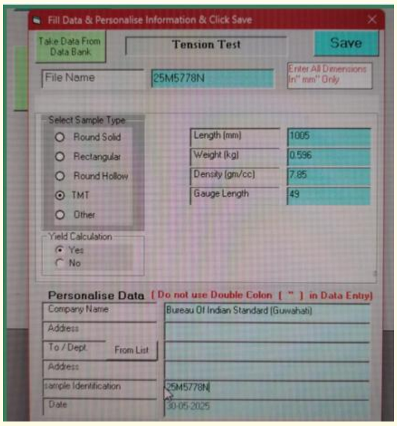
Fig. : On right Shows sample after testing and fracture, we measure gauge length at fracture after joining the sample.

3.2.7. Tensile & Yield Strength Testing (Clause 9.2)

Determine Yield stress (YS), Tensile stress (TS), and Percentage elongation of IS 2062 sample:

Tensile Testing procedure:

1) Data Entry in Computer: Input initial data like Sample ID, Length(mm), Weight (kg), Density, Initial Gauge length.



2) Specimen Mounting: Secure the prepared specimen between the UTM grips, ensuring proper alignment along the loading axis.
   a. T**est pieces must be gripped using suitable devices** such as wedge grips, screw grips, parallel jaws, or shouldered holders, ensuring the **tensile force is applied axially** to avoid bending, which can affect results—especially for brittle materials or when determining yield/proof strength.
   b. A **preliminary aligning force** (not exceeding **5% of the expected yield strength**) may be applied before testing; if used, **extension correction** must be made to exclude any deformation caused by this initial force.

3) Machine setup: Ensure safety shields are in place and the machine is ready for testing.
   1. **The force-measuring system must be zeroed after assembling the loading setup but before gripping the test piece**, so that the system excludes the weight of the grips and any clamping effects from the measurement.
   2. **Once set, the zero point must remain unchanged throughout the test**, ensuring that only the **actual tensile force** applied to the specimen is recorded accurately.

4) Loading Process: The machine applies load gradually until the specimen fractures.
5) Post-Fracture Measurements: Remove the broken specimen and measure the final gauge length using vernier or extensometer
6) Final data entry: Input the final gauge length into the computer to calculate elongation % and complete the test report.

3.2.8. Data Collection and Calculation

I. Calculate Nominal Mass (Linear Density) = $\frac{M}{L}$ (in Kg/m)

II. Measured Cross-Sectional Area and Gauge Length.

III. Calculation of Yield Stress $R_P = \frac{F_{YIELD}}{CSA}$ (in MPa)

IV. Calculation of Tensile Strength $R_M = \frac{F_{ULTIMATE}}{CSA}$ (in MPa)

V. Determine Stress Ratio $= \frac{R_M}{R_P}$

VI. Calculate Percentage Elongation at Fracture $\in = \frac{\Delta L}{L_o} \times 100\%$ **, where** $\Delta L = L_f - L_o$

- $L_f \rightarrow$ Gauge Length after Fracture
- $L_o \rightarrow$ Initial Gauge Length

3.2.9. Verification of Result and Tolerance Check

The **measured mechanical properties** (e.g. yield strength, tensile strength, elongation) must be **verified against the specified values** in IS 2062 Cl 10.3 and Table 2 as shown below:

Table 2 Mechanical Properties
(*Clauses* 5, 10.3, 10.3.1, 11.3.1, 12.2 *and* 12.4)

Grade Designation	Quality	Tensile Strength R_m, *Min* MPa[1)] (*See* Note 1)	Yield Stress R_{eH}, *Min* MPa[1)]			Percentage Elongation *A*, *Min* at Gauge Length, L_o=5.65	Internal Bend Diameter *Min* (*See* Note 2)		Charpy Impact Test (*See* Note 3)	
			<20	20-40	>40		≤ 25	>25	Temp °C	*Min* J
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
E 250	A	410	250	240	230	23	2*t*	3*t*	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27
E 275	A	430	275	265	255	22	2*t*	3*t*	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27

Table 4 Indian Standards Which Give Nominal Dimensions of Rolled Steel Products

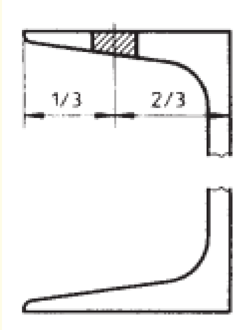
Sl No. (1)	Products (2)	Relevant Indian Standard (3)
i)	Beam, column, channel and angle sections	IS 808
ii)	Tee bars	IS 1173
iii)	Bulb angles	IS 1252
iv)	Plates, strips and flats	IS 1730

3.2.10. Sample test report and measured data

Channel Section 150× 75 :

Step-1: Take Mass and Length of the channel section and calculate Nominal Mass and check the tolerance.

Step-2: Mark the Dumble and cut the test piece from the channel section in the from the specified place as mentioned in IS 2062.

Fig. 

Step-3: Measure the width and thickness form an average of 4-5 readings, and find the Cross-Sectional area of the sample piece.

W (in mm)	t (in mm)
25.18	6.326
24.90	6.344
24.25	6.365
24.44	6.376
Average: 24.6925 mm	Average: 6.35275 mm

$$CSA = w\times t = 24.6925\times 6.35275 = 156.865\ mm^2$$

$$GL = 5.65\times \sqrt{CSA} = 70.7\ mm \cong\ 71\ mm$$

Step-4: Mark the gauge length on piece and punch GL on it carefully.

Fig. *Shows how gauge length is marked on the test piece with the help of vernier*

Step-5: Now turn on the UTM machine and in UTM software input the data (Width, Thickness and GL) in the software. Carefully fix the piece in the UTM and start the machine. Set the residual load close to 0, and tare it. Now start testing and increase load with the help of Knob and hold the lock of Movable cross head so that the lower jaw or teeth does not slip at the time of testing.

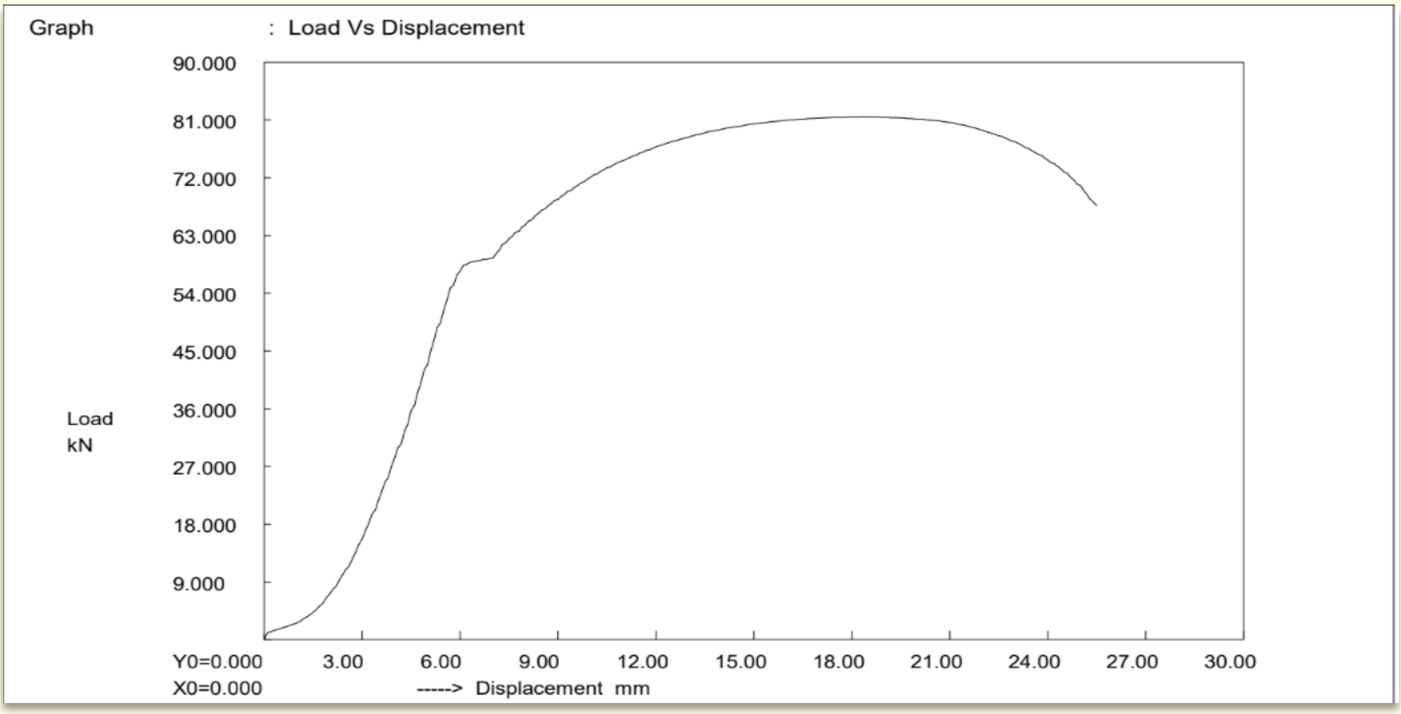
Step-6: Record the data as stated in 3.2.8. Measure the gauge length at the fracture

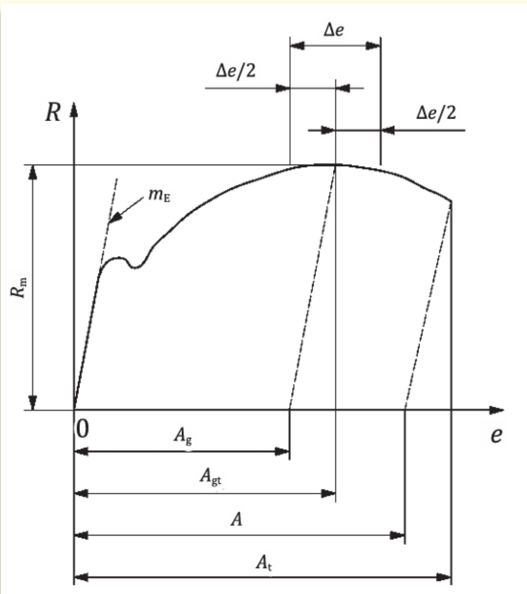
Calculation of Yield Stress $\boldsymbol{R_e} = \mathbf{373.044\ MPa}$

Calculation of Yield Stress $\boldsymbol{R_{\mathrm{m}}} = \mathbf{519.406\ MPa}$

The result shows that yield strength and tensile strength are sufficiently in accordance to the IS 2062 Table 2.

Grade Designation	Quality	Tensile Strength R_m, *Min* MPa[1] (*See* Note 1)	Yield Stress R_{eH}, *Min* MPa[1]			Percentage Elongation *A*, *Min* at Gauge Length, L_o=5.65	Internal Bend Diameter *Min* (*See* Note 2)		Charpy Impact Test (*See* Note 3)	
			<20	20-40	>40		≤ 25	>25	Temp °C	*Min* J
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
E 250	A	410	250	240	230	23	2*t*	3*t*	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27





Where,

A: percentage elongation after fracture

Ag: percentage plastic extension at maximum force

A_{gt}: percentage total extension at maximum force **At**: percentage total extension at fracture

e: percentage extension

m_E: slope of the elastic part of the stress-percentage extension curve

R: stress

Rm: tensile strength

Δe: plateau extent

CHAPTER 4: COMPARATIVE ANALYSIS AND DATA RECORDED

FOR IS 1786: 2008 WE WILL ANALYZE MEASUREMENT UNCERTAINTY FOR NOMINAL MASS, TENSILE STRENGTH, YIELD STRENGTH AND RIB AREA.

4.1.1 NOMINAL MASS

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL	Tested By:	Kartik Jaiswal
PRODUCT IS	2062	Temperature:	27±2° C
PARAMETER	NOMINAL MASS		

NOMINAL MASS = M/L M= MASS Kg L= LENGTH meters(m)

U(Nominal Mass)/Average(Nominal mass)=SQRT((u_Mass/Avg_Mass)^2 + (u_Length/Avg_Length)^2)

(A) Uncertainty in Length (L) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	1.007		0.0008	6.4E-07			
2	1.006		-0.0002	4E-08			
3	1.006	1.0062	-0.0002	4E-08	0.000447214	0.0002	m
4	1.006		-0.0002	4E-08			
5	1.006		-0.0002	4E-08			
			∑(xi - xm)2=	8E-07			

(B) Uncertainty in LENGTH (L) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
MEASURING TAPE	0.00028	m	2	0.001	mm	NA

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of Length u(x1)	0.000447214	Type A	Normal	√n	2.236067977	0.0002	4E-08	4	-0.0001753	mm
Uncertainty of Tape u(x2)	0.00028	Type B	Rectangular	2	2	0.00014	1.96E-08	∞	1	mm
Least count for Tape u(x3)	0.001	Type B	Rectangular	√3	1.732050808	0.00057735	3.33333E-07	∞	1	mm

N= M/L

c1= dx/dL= -0.876497736 cl*u1= -0.0001753

Combined Uncertainty (uL) = SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2) = 0.000626844 m

(A) Uncertainty in Mass(M) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	0.892		0.0046	2.116E-05			
2	0.9		0.0126	0.00015876			
3	0.888	0.8874	0.0006	3.6E-07	0.01485934	0.006645299	Kg
4	0.862		-0.0254	0.00064516			
5	0.895		0.0076	5.776E-05			
			∑(xi - xm)2=	0.0008832	Kg^2		

(B) Uncertainty in Mass (M) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
Digital Balance 15 Kg	0.008	Kg	2	0.002	kg	NA

Nominal Mass

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	0.886503677		0.004571656	2.09E-05			
2	0.894454383		0.012522361	0.00015681			
3	0.882528324	0.881932021	0.000596303	3.55577E-07	0.01476778	0.006604352	Kg/m
4	0.856688531		-0.02524349	0.000637234			
5	0.889485192		0.00755317	5.70504E-05			

∑(xi - xm)2= 0.000872349 Kg^2

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of Mass u(x4)	0.01485934	Type A	Normal	√n	2.236067977	0.006645299	4.416E-05	4	0.006604352	Kg
Repeatability of Nominal Mass u(x5)	0.01476778	Type A	Normal	√n	2.236067977	0.006604352	4.36175E-05	4	1	Kg/m
Uncertainty of Balance u(x6)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	Kg
Least count for Balance u(x7)	0.002	Type B	Normal	√n	2.236067977	0.000894427	0.0000008	∞	1	Kg

c2=dx/dM= 0.993838203 c2*u4= 0.006604352

Combined Uncertainty (uM) = SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2)

Combined uncertainty for Nominal Mass = U(Nominal Mass)/Average(Nominal mass)=SQRT((u_Mass/Avg_Mass)^2 + (u_Length/Avg_Length)^2)

u(M)= 0.0076 Kg

Uc= 0.007573127 Kg/m

5.01931E-05

Effective Degree of Freedom= Uc ^4 / (u (L)*c1)^4/v1) + (u (M)*c2) ^4/v2) = 4.042329169

Coverage factor K at = 95% Confidence Level, K = 2.776

Expanded Uncertainty = Combined Uncertainity (Uc) x Coverage Factor 0.021023001 Kg/m

The value of Nominal is 0.8819±0.021- Kg/m with coverage factor k= 2.776
for confidence level of 95%

MU in % =± 2.383743877 %

K value calculation from Student t-table

Student t-table

df	80%	90%	95%	99%
1	3.078	6.314	12.706	63.657
2	1.886	2.920	4.303	9.925
3	1.638	2.353	3.182	5.841
4	1.533	2.132	2.776	4.604
5	1.476	2.015	2.571	4.032
6	1.440	1.943	2.447	3.707
7	1.415	1.895	2.365	3.500
8	1.397	1.860	2.306	3.355
9	1.383	1.833	2.262	3.250
10	1.372	1.812	2.228	3.169
11	1.363	1.796	2.201	3.106
12	1.356	1.782	2.179	3.055
13	1.350	1.771	2.160	3.012
14	1.345	1.761	2.145	2.977
15	1.341	1.753	2.131	2.947

Student t-table

df	80%	90%	95%	99%
16	1.337	1.746	2.120	2.921
17	1.333	1.740	2.110	2.898
18	1.330	1.734	2.101	2.878
19	1.328	1.729	2.093	2.861
20	1.325	1.725	2.086	2.845
21	1.323	1.721	2.080	2.831
22	1.321	1.717	2.074	2.819
23	1.319	1.714	2.069	2.807
24	1.318	1.711	2.064	2.797
25	1.316	1.708	2.060	2.787
26	1.315	1.706	2.056	2.779
27	1.314	1.703	2.052	2.771
28	1.313	1.701	2.048	2.763
29	1.311	1.699	2.045	2.756
30	1.310	1.697	2.042	2.750

df	80%	90%	95%	99%
infinity	1.282	1.645	1.96	2.576

Given:

- Effective degrees of freedom: $v_{eff} = 4.042329169$

- 95 % two-tailed Student's t values:

$t_4 = 2.776$

$t_5 = 2.571$

1. Compute Δv*:*

$\Delta v = v_{eff} - 4$

$\Delta v = 4.042329169 - 4$

$\Delta v = 0.042329169$

2. Compute Δt*:*

$\Delta t = t_5 - t_4$

$\Delta t = 2.571 - 2.776$

$\Delta t = -0.205$

3. Interpolate k:

$k = t_4 + \Delta v \times \Delta t$

$k = 2.776 + (0.042329169 \times -0.205)$

$k = 2.776 - 0.008677338$

$k \approx 2.776$

4.1.2 TENSILE STRENGTH

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL	Tested By:	Kartik Jaiswal
PRODUCT IS	1786	Temperature:	27° C
PARAMETER	TENSILE STRENGTH		

TENSILE STRENGTH = F/A F= FORCE KN A= CROSS-SECTIONAL AREA mm^2

U(TENSILE STRENGTH)/Average(TENSILE STRENGTH)=SQRT((u_Force/Avg_Force)^2 + (u_Area/Avg_Area)^2)

(A) Uncertainty in AREA (A) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	112.841		0.493	0.243049			
2	113.966		1.618	2.617924			
3	112.446	112.348	0.098	0.009604	1.873662056	0.837927145	mm^2
4	109.154		-3.194	10.201636			
5	113.333		0.985	0.970225			
			∑(xi - xm)2=	14.042438			

(B) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of Length u(x1)	1.873662056	Type A	Normal	√n	2.236067977	0.837927145	0.7021219	4	-5.324411305	mm
Uncertainty of CALIPER u(x2)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	mm
Least count for CALIPER u(x3)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x4)	0.02	Type B	Rectangular	√3	1.732050808	0.011547005	0.000133333	∞	1	
Rm= F/A					Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c1= dx/dA=	-6.35426521	cl*u1=	-5.324411305				0.838034228	mm		

(C) Uncertainty in FORCE(F) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	78460		-1744	3041536			
2	79060		-1144	1308736			
3	78260	80204	-1944	3779136	2895.354901	1294.842075	N
4	85240		5036	25361296			
5	80000		-204	41616			
			∑(xi - xm)2=	33532320 N^2			

(B) Uncertainty in FORCE(F) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy	CAPAITY
UTM-40	0.372	%	2	20	N	1%OFrEADING	400000

TENSILE STRENGTH

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	698.365792		-15.52319578	240.9696074			
2	703.706341		-10.18264678	103.6862954			
3	696.585609	713.8889878	-17.30337879	299.4069175	25.77130791	11.52527927	N/mm^2
4	758.7139958		44.82500801	2009.281343			
5	712.0732011		-1.815786663	3.297081205			

∑(xi - xm)2= 2656.641245 (N/mm^2)^2

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of TENSILE STRENGTH u(	2895.354901	Type A	Normal	√n	2.236067977	1294.842075	1676616	**4**	**11.52527927**	**N**
Repeatability of LOAD u(x5)	25.77130791	Type A	Normal	√n	2.236067977	11.52527927	132.8320622	4	1	N/mm^2
Uncertainty of UTM u(x6)	1488	Type B	Normal	2	2	744	553536	∞	1	N
Least count for UTM u(x7)	20	Type B	Rectangular	√3	1.732050808	11.54700538	133.3333333	∞	1	N
Accuracy of UTM u(x8)	**802.04**	Type B	Rectangular	√3	**1.732050808**	**463.0580099**	**214422.7205**	∞	1	
c2=dx/dF=	**0.008900915**	c2*u4=	**11.52527927**							

Combined Uncertainty (uM) = SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2+u(x8)^2)

Combined uncertainty for Tensile Strength = Average(TENSILE STRENGTH)*(SQRT((u_Force/Avg_Force)^2 + (u_Area/Avg_Area)^2))

u(M)= 1563.55622 N

Uc= **14.90106528 Kg/m**

18020.42209

Effective Degree of Freedom= Uc ^4 / (u (L)*c1)^4/v1) + (u (M)*c2) ^4/v2) = **5.146666936**

Coverage factor K at = 95% Confidence Level, K = 2.553 From Student-t table

Expanded Uncertainty = Combined Uncertainity (Uc) x Coverage Factor 38.04241967 N/mm^2

The value of TENSILE STRENGTH is 713.8889 ±38.0424 N/mm^2 with coverage factor k= 2.553
for confidence level of 95%

MU in % = ± 5.328898515 %

4.1.3 YIELD STRENGTH

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HIGH STRENGTH DEFORMED STEEL BARS AND WIRES FOR	Tested By:	Kartik Jaiswal
PRODUCT IS	1786	Temperature:	27° C
PARAMETER	YIELD STRENGTH		

TENSILE STRENGTH = F/A   F= FORCE KN   A= CROSS-SECTIONAL AREA mm^2

U(TENSILE STRENGTH)/Average(TENSILE STRENGTH)=SQRT((u_Force/Avg_Force)^2 + (u_Area/Avg_Area)^2)

(A) Uncertainty in AREA (A) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	112.841		0.493	0.243049			
2	113.966		1.618	2.617924			
3	112.446	112.348	0.098	0.009604	1.873662056	0.837927145	mm^2
4	109.154		-3.194	10.201636			
5	113.333		0.985	0.970225			
			∑(xi - xm)2=	14.042438			

(B) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of Length u(x1)	1.873662056	Type A	Normal	√n	2.236067977	0.837927145	0.7021219	4	-4.669315664	mm
Uncertainty of CALIPER u(x2)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	mm
Least count for CALIPER u(x3)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x4)	0.02	Type B	Rectangular	√3	1.732050808	0.011547005	0.000133333	∞	1	
Rm= F/A					Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c1= dx/dA=	-5.572460199	cl*u1=	-4.669315664				0.838034228	mm		

(C) Uncertainty in FORCE(F) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	69780		-556	309136			
2	70480		144	20736			
3	68820	70336	-1516	2298256	1194.102173	534.0187263	N
4	72080		1744	3041536			
5	70520		184	33856			
			∑(xi - xm)2=	5703520	N^2		

(B) Uncertainty in FORCE(F) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy	CAPAITY
UTM-40	0.372	%	2	20	N	1%OFrEADING	400000

TENSILE STRENGTH

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	621.1058497		-4.948908748	24.49169779			
2	627.3364902		1.281731762	1.64283631			
3	612.5609713	626.0547584	-13.49378716	182.082292	10.62860196	4.753255298	N/mm^2
4	641.5779542		15.52319578	240.9696074			
5	627.6925268		1.637768363	2.682285209			
			∑(xi - xm)2=	451.8687186	(N/mm^2)^2		

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of TENSILE STRENGTH	1194.102173	Type A	Normal	√n	2.236067977	534.0187263	285176	4	**4.753255298**	**N**
Repeatability of LOAD u(x5)	10.62860196	Type A	Normal	√n	2.236067977	4.753255298	22.59343593	4	1	**N/mm^2**
Uncertainty of UTM u(x6)	1488	Type B	Normal	2	2	744	553536	∞	1	**N**
Least count for UTM u(x7)	20	Type B	Rectangular	√3	1.732050808	11.54700538	133.3333333	∞	1	**N**
Accuracy of UTM u(x8)	**703.36**	Type B	Rectangular	√3	**1.732050808**	**406.0850853**	**164905.0965**	∞	1	
c2=dx/dF=	**0.008900915**	c2*u4=	**4.753255298**			Combined Uncertainty (uM) =	SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2+u(x8)^2			

Combined uncertainty for Tensile Strength =	**Average(TENSILE STRENGTH)*(SQRT((u_Force/Avg_Force)^2 + (u_Area/Avg_Area)^2))**		u(M)=	1001.87346	N
Uc=	**10.06635497 Kg/m**				
				4762.160332	
Effective Degree of Freedom=	Uc ^4 / (u (L)*c1)^4/v1) + (u (M)*c2) ^4/v2)	=	**6.040427908**		
Coverage factor K at =	95% Confidence Level, K =	2.444	From Student-t table		
Expanded Uncertainty =	Combined Uncertainity (Uc) x Coverage Factor		24.60217154 N/mm^2		

The value of TENSILE STRENGTH is 626.0547 ±24.6022 - N/mm^2 with coverage factor k= 2.444	
for confidence level of 95%	
MU in % = ±	**3.929715606 %**

4.1.4 Mean Rib Area

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	**HIGH STRENGTH DEFORMED BARS AND WIRES FOR CONCRETE REINFORCEMENT**	**Tested By:**	**Kartik Jaiswal**
PRODUCT IS	**1786:2008**	**Temperature:**	**27° C**
PARAMETER	**Mean Rib Area**		

Mean Rib Area=	**(2*Ltr*Dtr*Sin(θ)/(3*Str)**	**Ltr=**	**Length of Rib**	**mm**	**Dtr=**	**Mean Height of Rib**	**mm**
		Sin(θ)=	**Angle**	**Radians**	**Str=**	**Length/Spacing**	**mm**

U(Mean Rib Area)/Average(Mean Rib Area)=SQRT((u_Ltr/Avg_Ltr)^2 + (u_Dtr/Avg_Dtr)^2+(u_Sin(θ)/Avg_Sin(θ))^2+(u_Str/Avg_Str)^2)

(A) Uncertainty in Ltr estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	20.577		0.053	0.002809			
2	20.528		0.004	1.6E-05			
3	20.208	20.524	-0.316	0.099856	0.196266401	0.087773003	mm
4	20.559		0.035	0.001225			
5	20.748		0.224	0.050176			
			∑(xi - xm)2=	**0.154082**			

(B) Uncertainty in Ltr estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of Length u(x1)	0.196266401	Type A	Normal	√n	2.236067977	0.087773003	0.0077041	4	0.003180378	**mm**
Uncertainty of CALIPER u(x2)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	**mm**
Least count for CALIPER u(x3)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x4)	**0.02**	Type B	Rectangular	√3	1.732050808	**0.011547005**	0.000133333	∞	**1**	
Ar=	(2*Ltr*Dtr*Sin(θ))/(3*Str)				Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c1= dx/dLtr=	0.036234122	cl*u(x1)=	**0.003180378**				**0.088789451**	mm		

(C) Uncertainty in Dtr estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	0.935		0.0543	0.0029485			
2	0.927		0.0463	0.0021437			
3	0.911	0.8807	0.0303	0.0009181	0.060938083	0.027252339	mm
4	0.827		-0.0537	0.0028837			
5	0.8035		-0.0772	0.0059598			
			∑(xi - xm)2=	**0.0148538**			

(D) Uncertainty in Dtr estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of Length u(x9)	0.060938083	Type A	Normal	√n	2.236067977	0.027252339	0.00074269	4	0.023012062	mm
Uncertainty of CALIPER u(x10)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	mm
Least count for CALIPER u(x11)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x12)	**0.02**	Type B	Rectangular	√3	1.732050808	**0.011547005**	0.000133333	∞	**1**	
Ar=	(2*Ltr*Dtr*Sin(θ))/(3*Str)				Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c2= dx/dDtr=	**0.844406852**	c2*u(x9)=	**0.023012062**				**0.030367033**	mm		

(E) Uncertainty in Sin(θ) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty		Cos(θ)	
					√∑(xi - xm)2/n - 1	SD/√n			
1	0.8705		0.00332	1.102E-05				**0.4921**	
2	0.8685		0.00132	1.742E-06				**0.4956**	
3	0.8601	0.86718	-0.00708	5.013E-05	0.00448464	0.002005592	mm	**0.5101**	**0.49792**
4	0.8711		0.00392	1.537E-05				**0.4912**	
5	0.8657		-0.00148	2.19E-06				**0.5006**	
			∑(xi - xm)2=	**8.045E-05**					

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of Length u(x13)	0.00448464	Type A	Normal	√n	2.236067977	0.002005592	4.0224E-06	4	0	mm
Ar=	(2*Ltr*Dtr*Sin(θ))/(3*Str)				Combined Uncertainty(u3)=	SQRT(u(x1)				
c4=dx/dStr=	**0.427002151**	c4*u(x13)				**0.002005592**	mm			

(F) Uncertainty in Str estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	14.054		0.00232	5.3824E-06			
2	14.0395		-0.01218	0.000148352			
3	14.1812	14.05168	0.12952	0.01677543	0.078157322	0.034953017	mm
4	13.9787		-0.07298	0.00532608			
5	14.005		-0.04668	0.002179022			
			∑(xi - xm)2=	**0.024434268**	**mm^2**		

(G) Uncertainty in Str estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit
UTM-40	0.008	mm	2	0.01	mm

Mean Rib Area

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	0.74639302		0.002691731	7.24542E-06			
2	0.745447264		0.001745975	3.04843E-06			
3	0.730860867	0.743701289	-0.012840422	0.000164876	0.007563294	0.003382408	mm^2/mm
4	0.750930895		0.007229606	5.22672E-05			
5	0.744874398		0.001173109	1.37619E-06			
			∑(xi - xm)2=	**0.000228814**	**(mm^2/mm)^2**		

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of Str u(x4)	0.078157322	Type A	Normal	√n	2.236067977	0.034953017	0.001221713	4	-0.001849849	mm
Repeatability of Mean Rib Area u(x5)	0.007563294	Type A	Normal	√n	2.236067977	0.003382408	1.14407E-05	4	1	mm^2/mm
Uncertainty of CALIPER u(x6)	0	Type B	Normal	2	2	0	0	∞	1	mm
Least count for CALIPER u(x7)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
c3=dx/dStr=	-0.052923858	c3*u(x4)=	-0.001849849				Combined Uncertainty (uM) =	SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2)		

Combined uncertainty for Tensile Strength =	U(Mean Rib Area)/Average(Mean Rib Area)=SQRT((u_Ltr/Avg_Ltr)^2 + (u_Dtr/Avg_Dtr)^2+(u_Sin(θ)/Avg_Sin(θ))^2+(u_Str/Avg_Str)^2			u(M)=	0.035426639 mm
	Uc=	0.004612004 mm^2/mm			
					6.55339E-05
Effective Degree of Freedom=	Uc ^4	=	15.14579047		
	(u (Ltr)*c1)^4/v1) + (u (Dtr)*c2) ^4/v2+ (u (Str)*c3) ^4/v3+ (u (Sin(θ))*c4) ^4/v4)				
Coverage factor K at =	95%	Confidence Level, K =	2.1294	From Student-t table	
Expanded Uncertainty =	Combined Uncertainity (Uc) x Coverage Factor			0.009820801 mm^2/mm	

The value of Mean rib Area 0.7437 ± 0.00982 mm^2/mm with coverage factor k= 2.1294
for confidence level of 95%
MU in % =± 1.320530372 %

Sensitivity Coefficient Calculation For Mean Rib Area

Given Formula for mean Rib Area Calculation

$$A_r = \frac{\frac{2}{3} \times L_{tr} \times D_{tr} \times \sin\theta}{S_{tr}}$$

So for all terms we will Calculate Sensitivity Coefficient

1) For $L_{tr} \rightarrow C_1 \times U_1$

$$C_1 = \frac{dx}{dL_{tr}} = \frac{2}{3} \times \frac{D_{tr} \times \sin\theta}{S_{tr}}$$

2) For $D_{tr} \rightarrow C_2 \times U_2$

$$C_2 = \frac{dx}{dD_{tr}} = \frac{2}{3} \times \frac{L_{tr} \times \sin\theta}{S_{tr}}$$

3) For Angle $\sin\theta$

$$C_3 = \frac{dx}{d\theta} = \frac{2}{3} \times \frac{L_{tr} \times D_{tr} \times \cos\theta}{S_{tr}}$$

4) For S_{tr}

$$C_4 = \frac{dx}{dS_{tr}} = -\frac{2}{3} \times \frac{L_{tr} \times D_{tr} \times \sin\theta}{(S_{tr})^2}$$

This is the hand calculation to show how we are calculating the sensitivity coefficient involved in the MU calculation, depending on the equation and the number of parameters we get the no. of coefficient.

FOR IS 2062: 2011 WE WILL ANALYZE MEASUREMENT UNCERTAINTY FOR NOMINAL MASS, TENSILE STRENGTH AND YIELD STRENGTH.

4.2.1 YIELD STRENGTH *IS FLAT*

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL	Tested By:	Kartik Jaiswal
PRODUCT IS	2062	Temperature:	27° C
PARAMETER	YIELD STRENGTH		

TENSILE STRENGTH = F/A F= FORCE KN A= CROSS-SECTIONAL AREA mm^2

A= wxt

U(YIELD STRENGTH)/Average(YIELD STRENGTH)=SQRT((u_Force/Avg_Force)^2+(u_Width/Avg_Width)^2+(u_Thickness/Avg_Thickness)^2)

(A) Uncertainty in WIDTH (W) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	30.08		-0.05	0.0025			
2	30.23		0.1	0.01			
3	30.02	30.13	-0.11	0.0121	0.081547532	0.036469165	mm
4	30.17		0.04	0.0016			
5	30.15		0.02	0.0004			
			∑(xi - xm)2=	0.0266			

(B) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of WIDTH u(x1)	0.081547532	Type A	Normal	√n	2.236067977	0.036469165	0.00133	4	-0.441217742	mm
Uncertainty of CALIPER u(x2)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	mm
Least count for CALIPER u(x3)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x4)	**0.02**	Type B	Rectangular	√3	1.732050808	**0.011547005**	0.000133333	∞	**1**	
Rm=	F/(wxt)				Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c1= dx/dw=	-12.09837793	c1*u1=	-0.441217742				**0.038851855**	mm		

(C) Uncertainty in FORCE(F) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	54460		-1600	2560000			
2	57420		1360	1849600			
3	56660	56060	600	360000	1102.633212	493.1125632	N
4	55760		-300	90000			
5	56000		-60	3600			
			∑(xi - xm)2=	4863200	N^2		

(B) Uncertainty in FORCE(F) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy	CAPAITY(N)
UTM-40	0.372	%	2	20	N	1% OF READING	400000

YIELD STRENGTH

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	354.1202989		-10.4038281	108.2396391			
2	373.3673809		8.843253884	78.20313926			
3	368.4255626	364.524127	3.901435537	15.22119925	7.169753996	3.206411463	N/mm^2
4	362.5734092		-1.950717769	3.805299813			
5	364.1339835		-0.390143554	0.152211993			

(C) Uncertainty in THICKNESS (T) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	5.042		-0.0622	0.00386884			
2	5.117		0.0128	0.00016384			
3	5.159	5.1042	0.0548	0.00300304	0.042055915	0.018807977	mm
4	5.098		-0.0062	3.844E-05			
5	5.105		0.0008	6.4E-07			
			∑(xi - xm)2=	0.0070748			

(D) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC EXTERNAL MICROMETER	0.0014	mm	2	0.001	mm	0.002

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of THICKNESS u(x1)	0.042055915	Type A	Normal	√n	2.236067977	0.018807977	0.00035374	4	-1.343199994	**mm**
Uncertainty of MICROMETER u(x2)	0.0014	Type B	Normal	√n	2.236067977	0.000626099	0.000000392	∞	1	**mm**
Least count for MICROMETER u(x3)	0.001	Type B	Rectangular	√3	1.732050808	0.00057735	3.33333E-07	∞	1	mm
Accuracy of MICROMETER u(x4)	**0.002**	Type B	Rectangular	√3	1.732050808	**0.001154701**	1.33333E-06	∞	**1**	
Rm=	**F/(w×t)**				**Combined Uncertainty (uL) =**		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c3= dx/dt=	**-71.41650543**	**c3*u3=**	**-1.343199994**				**0.018862626**	mm		

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient C i	
Repeatability of TENSILE STRENGTH	1102.633212	Type A	Normal	√n	2.236067977	493.1125632	243160	**4**	**3.206411463**	**N**
Repeatability of LOAD u(x5)	7.169753996	Type A	Normal	√n	2.236067977	3.206411463	10.28107447	4	1	**N/mm^2**
Uncertainty of UTM u(x6)	1488	Type B	Normal	2	2	744	553536	∞	1	**N**
Least count for UTM u(x7)	20	Type B	Rectangular	√3	1.732050808	11.54700538	133.3333333	∞	1	**N**
Accuracy of UTM u(x8)	560.6	Type B	Rectangular	√3	1.732050808	323.6625609	104757.4533	∞	1	
c2=dx/dF=	**0.006502393**	**c2*u4=**	**3.206411463**				Combined Uncertainty (uM) =	SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2+u(x8)^2)		

Combined uncertainty for YIELD Strength = YIELD STRENGTH)/Average(YIELD STRENGTH)=SQRT((u_Force/Avg_Force)^2 + (u_Width/Avg_Width)^2+(u_Thickness/Avg_Thickness)

u(M)= 949.5192398 N

Uc= 6.336853878 N/mm^2

3044.549375

Effective Degree of Freedom= Uc ^4 / ((u (w)*c1)^4/v1) + (u (F)*c2) ^4/v2 + (u (t)*c3) ^4/v3) = **4.438460471**

Coverage factor K at = 95% **Confidence Level, K =** **2.686** **From Student-t table**

Expanded Uncertainty = Combined Uncertainity (Uc) x Coverage Factor 17.02078952 N/mm^2

The value of YIELD STRENGTH is364.52412701706 ± 17.020789515606N/mm^2 with coverage factor k= 2.686
for confidence level of 0.95

MU in % =± 4.669317681 %

4.2.2 TENSILE STRENGTH

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL	Tested By:	Kartik Jaiswal
			IIT BBS B.TECH - 3RD YEAR
PRODUCT IS	2062	Temperature:	27° C
PARAMETER	TENSILE STRENGTH		

TENSILE STRENGTH = F/A F= FORCE KN A= CROSS-SECTIONAL AREA mm^2

A= w×t

U(TENSILE STRENGTH)/Average(TENSILE STRENGTH)=SQRT((u_Force/Avg_Force)^2 + (u_Width/Avg_Width)^2+(u_Thickness/Avg_Thickness)^2)

(A) Uncertainty in WIDTH (W) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	30.08		-0.05	0.0025			
2	30.23		0.1	0.01			
3	30.02	30.13	-0.11	0.0121	0.081547532	0.036469165	mm
4	30.17		0.04	0.0016			
5	30.15		0.02	0.0004			
			∑(xi - xm)2=	0.0266			

(B) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC CALIPER	0.008	mm	2	0.01	mm	0.02

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of WIDTH u(x1)	0.081547532	Type A	Normal	√n	2.236067977	0.036469165	0.00133	4	-0.611376992	mm
Uncertainty of CALIPER u(x2)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	mm
Least count for CALIPER u(x3)	0.01	Type B	Rectangular	√3	1.732050808	0.005773503	3.33333E-05	∞	1	mm
Accuracy of Calipers u(x4)	0.02	Type B	Rectangular	√3	1.732050808	0.011547005	0.000133333	∞	1	
Rm= F/(w×t)					Combined Uncertainty (uL) =		SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c1= dx/dw=	-16.76421687	c1*u1=	-0.611376992				0.038851855	mm		

(E) Uncertainty in THICKNESS (T) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	5.042		-0.0622	0.0038688			
2	5.117		0.0128	0.0001638			
3	5.159	5.1042	0.0548	0.003003	0.042055915	0.018807977	mm
4	5.098		-0.0062	3.844E-05			
5	5.105		0.0008	6.4E-07			
			∑(xi - xm)2=	0.0070748			

(F) Uncertainty in AREA (A) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
DIGIMATIC EXTERNAL MICROMETER	0.0014	mm	2	0.001	mm	0.002

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of THICKNESS u(x1)	0.04205592	Type A	Normal	√n	2.236067977	0.018807977	0.00035374	4	-1.861216117	mm
Uncertainty of MICROMETER u(x2)	0.0014	Type B	Normal	√n	2.236067977	0.000626099	0.000000392	∞	1	mm
Least count for MICROMETER u(x3)	0.001	Type B	Rectangular	√3	1.732050808	0.00057735	3.33333E-07	∞	1	mm
Accuracy of MICROMETER u(x4)	0.002	Type B	Rectangular	√3	1.732050808	0.001154701	1.33333E-06	∞	1	
Rm= F/(w×t)				Combined Uncertainty (uL) =			SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2+u(x4)^2)			
c3= dx/dt=	-98.958868	c3*u3=	-1.861216117				0.018862626	mm		

(C) Uncertainty in FORCE(F) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	76260		-1420	2016400			
2	78780		1100	1210000			
3	78080	77680	400	160000	920.6519429	411.7280656	N
4	77620		-60	3600			
5	77660		-20	400			
			∑(xi - xm)2=	**3390400**	**N^2**		

(D) Uncertainty in FORCE(F) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy	CAPAITY(N)
UTM-40	0.372	%	2	20	N	1% OF READING	400000

TENSILE STRENGTH

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD	Std. uncertainty	
					√∑(xi - xm)2/n - 1	SD/√n	
1	495.8724568		-9.233397438	85.25562824			
2	512.258486		7.152631818	51.16014192			
3	507.7068112	505.1058542	2.600957025	6.764977445	5.986440346	2.677217511	**N/mm^2**
4	504.7157107		-0.390143554	0.152211993			
5	504.9758064		-0.130047851	0.016912444			
			∑(xi - xm)2=	**143.349872**	**(N/mm^2)^2**		

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom	Sensitivity coefficient	C i
Repeatability of TENSILE STRENGTH	920.6519429	Type A	Normal	√n	2.236067977	411.7280656	169520	**4**	**2.677217511**	N
Repeatability of LOAD u(x5)	5.986440346	Type A	Normal	√n	2.236067977	2.677217511	7.167493602	4	1	N/mm^2
Uncertainty of UTM u(x6)	1488	Type B	Normal	2	2	744	553536	∞	1	N
Least count for UTM u(x7)	20	Type B	Rectangular	√3	1.732050808	11.54700538	133.3333333	∞	1	N
Accuracy of UTM u(x8)	776.8	Type B	Rectangular	√3	1.732050808	448.4856891	201139.4133	∞	1	
c2=dx/dF=	**0.006502393**	**c2*u4=**	**2.677217511**				Combined Uncertainty (uM) =	T (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2+u(x8		

Combined uncertainty for Tensile Strength = STRENGTH)/Average(TENSILE STRENGTH)=SQRT((u_Force/Avg_Force)^2 + (u_Width/Avg_Width)^2+(u_Thickness/Avg_Thi

u(M)= 961.4201718 N

Uc= 6.55668736 N/mm^2

2573.930919

Effective Degree of Freedom= Uc ^4 / ((u (w)*c1)^4/v1) + (u (F)*c2) ^4/v2 + (u (t)*c3) ^4/v3) = **4.839506379**

Coverage factor K at = 95% Confidence Level, K = 2.571 **From Student-t table**

Expanded Uncertainty = Combined Uncertainity (Uc) x Coverage Factor 16.8572432 N/mm^2

The value of TENSILE STRENGTH is505.10585420416 ± 16.857243201667N/mm^2 with coverage factor k= 2.571 for confidence level of 0.95

MU in % = ± 3.337368407 %

4.2.3 NOMINAL MASS

BUREAU OF INDIAN STANDARDS GUWAHATI LABORATORY

UNCERTAINTY CALCULTAIONS

PRODUCT	HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL	Tested By:	Kartik Jaiswal
PRODUCT IS	2062	Temperature:	27±2° C
PARAMETER	NOMINAL MASS		

NOMINAL MASS = M/L M= MASS Kg L= LENGTH meters(m)

U(Nominal Mass)/Average(Nominal mass)=SQRT((u_Mass/Avg_Mass)^2 + (u_Length/Avg_Length)^2)

(A) Uncertainty in Length (L) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	1		-0.0004	1.6E-07			
2	1		-0.0004	1.6E-07			
3	1.002	1.0004	0.0016	2.56E-06	0.001140175	0.000509902	m
4	1.001		0.0006	3.6E-07			
5	0.999		-0.0014	1.96E-06			
			∑(xi - xm)2=	5.2E-06			

(B) Uncertainty in LENGTH (L) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
MEASURING TAPE	0.00028	m	2	0.001	mm	NA

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y) ^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of Length u(x1)	0.001140175	Type A	Normal	√n	2.236067977	0.000509902	2.6E-07	4	-0.000587753	mm
Uncertainty of Tape u(x2)	0.00028	Type B	Rectangular	2	2	0.00014	1.96E-08	∞	1	mm
Least count for Tape u(x3)	0.001	Type B	Rectangular	√3	1.732050808	0.00057735	3.33333E-07	∞	1	mm

N= M/L

c1= dx/dL= -1.152677673 cl*u1= -0.000587753

Combined Uncertainty (uL) = SQRT (u(x1)^2 + u(x2) ^2+u(x3)^2)

0.000782901 m

(A) Uncertainty in Mass(M) estimation (Type A):

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	1.146		-0.0076	5.776E-05			
2	1.17		0.0164	0.00026896			
3	1.172	1.1536	0.0184	0.00033856	0.017572706	0.007858753	Kg
4	1.15		-0.0036	1.296E-05			
5	1.13		-0.0236	0.00055696			
			∑(xi - xm)2=	0.0012352	Kg^2		

(B) Uncertainty in Mass (M) estimation (Type B):

Equipment's	Declared MU	Declared Unit	At Factor K =	Least Count	Unit	Accuracy
Digital Balance 15 Kg	0.008	Kg	2	0.002	kg	NA

Nominal Mass

S.NO.	Result (xi)	Mean (xm)	xi - xm	(xi - xm)2	SD √∑(xi - xm)2/n - 1	Std. uncertainty SD/√n	
1	1.145541783		-0.007596961	5.77138E-05			
2	1.169532187		0.016393443	0.000268745			
3	1.171531387	1.153138745	0.018392643	0.000338289	0.01756568	0.007855611	Kg/m
4	1.149540184		-0.003598561	1.29496E-05			
5	1.129548181		-0.023590564	0.000556515			
			∑(xi - xm)2=	0.001234212	Kg^2		

Sources of Uncertainty	Value	Type Of Disrtibution	Probability Distribution	Divisor	Divisor Value	Standard Uncertainty	Uncertainty Contribution U(y)^2	Degrees of freedom V	Sensitivity coefficient Ci	
Repeatability of Mass u(x4)	0.017572706	Type A	Normal	√n	2.236067977	0.007858753	6.176E-05	**4**	**0.007855611**	**Kg**
Repeatability of Nominal Mass u(x5)	0.01756568	Type A	Normal	√n	2.236067977	0.007855611	6.17106E-05	4	1	**Kg/m**
Uncertainty of Balance u(x6)	0.008	Type B	Normal	√n	2.236067977	0.003577709	0.0000128	∞	1	**Kg**
Least count for Balance u(x7)	0.002	Type B	Normal	√n	2.236067977	0.000894427	0.0000008	∞	1	**Kg**

c2=dx/dM= **0.99960016** **c2*u4=** **0.007855611**

Combined Uncertainty (uM) = SQRT (u(x4)^2 + u(x5) ^2 +u(x6) ^2 +u(x7) ^2)

Combined uncertainty for Nominal Mass = **U(Nominal Mass)/Average(Nominal mass)=SQRT((u_Mass/Avg_Mass)^2 + (u_Length/Avg_Length)^2)**

u(M)= 0.008681014 Kg

Uc= 0.008724341 Kg/m

6.81947E-05

Effective Degree of Freedom= Uc ^4 / (u (L)*c1)^4/v1) + (u (M)*c2) ^4/v2) **= 4.086511665**

Coverage factor K at = 95% Confidence Level, K = 2.75

Expanded Uncertainty = **Combined Uncertainity (Uc) x Coverage Factor** 0.023991939 Kg/m

The value of Nominal is 1.1531±0.02399- Kg/m with coverage factor k= 2
for confidence level of 95%

MU in % =± 2.080576928 %

CHAPTER 5: Conclusion and Discussion

The internship focused on the detailed evaluation of **measurement uncertainty (MU)** in the determination of mechanical and physical properties of steel as per **IS 1786** and **IS 2062**. The testing was conducted in accordance with **IS/ISO/IEC 17025** guidelines to ensure traceability, consistency, and validation of methods.

IS	Parameter	Result	MU (in %)	Previous Value of Lab
1786: 2008	Nominal Mass	0.8819 Kg/m	2.38%	2.42%
	Tensile Strength	713.88 N/mm^2	5.32%	4.68%
	Yield Strength	626.05 N/mm^2	3.929%	4.43%
	Mean Rib Area	0.7437 mm^2/mm	1.321%	NA
2062: 2011	Nominal Mass	1.1531 Kg/m	2.081%	1.0%
	Tensile Strength	505.105 N/mm^2	3.337%	5.85%
	Yield Strength	364.52 N/mm^2	4.66%	4.5%

The results obtained from the current test exhibit some variations when compared to the previous laboratory values, reflecting possible changes in material properties or testing conditions. While some parameters—such as the tensile and yield strength under IS 1786:2008—have shown an increase, others under IS 2062:2011 reveal a decrease. Notably, the measurement uncertainties (MU) differ between the two sets of data, suggesting subtle shifts in testing precision or methodology. All analyses and calibrations were carried out in accordance with the requirements of ISO/IEC 17025:2017, ensuring the competence of the laboratory, the validity of methods, and the traceability of measurement results. These variations highlight the importance of regular monitoring, interlaboratory comparisons, and proficiency testing to maintain material consistency and adherence to standards. Further investigation could focus on whether batch-to-batch variability, process adjustments, or environmental factors are driving these differences. Continuous tracking and comparison with historical data remain essential for robust quality assurance and ongoing improvement of process control.

Key Observations

- **Repeatability Reduces MU**: It was observed that increasing the number of repeated measurements on the same sample consistently led to a reduction in MU. This demonstrates the importance of consistency in measurement procedures.
- **Fewer Instruments = Less MU**: When fewer instruments were used (especially a single instrument for rib area measurement), the MU was found to be significantly lower. This is due to reduced inter-instrument variability and improved calibration consistency.
- **More Instruments = More MU**: As the number of instruments increased for testing parameters like tensile and yield strength, the MU also increased. This highlights the role of standardization and calibration in maintaining low uncertainty.

Future Scope

- **Development of MU Optimization Models**: The study can be extended to develop predictive models for MU based on factors such as instrument type, operator variability, environment, and repeatability.
- **Integration of Machine Learning in MU Analysis**: AI/ML algorithms can be introduced to identify patterns in uncertainty data and predict MU ranges for similar test scenarios.
- **Expansion to Other Materials**: This method can be applied to non-ferrous metals, composite materials, and other engineering alloys to improve reliability across different standards.
- **Inter-Laboratory Comparisons (ILC)**: Performing ILCs and proficiency testing with other accredited labs can further validate the calculated MU and help in benchmarking best practices.

Engineering Applications

- **Quality Control in Manufacturing**: Accurate estimation of MU helps manufacturers maintain product quality within defined limits and avoid unnecessary rejections.
- **Structural Safety Assurance**: Knowing the uncertainty in mechanical properties allows structural engineers to include safety factors that are both economical and adequate.
- **Standardization and Certification**: MU analysis is critical for laboratories seeking **NABL accreditation** under IS/ISO/IEC 17025, ensuring reliability and legal acceptance of test results.
- **Support for Design Codes**: MU values can be used to refine partial safety factors in design codes and limit state methods used in civil and structural engineering.

Limitations

- **Environmental Factors Not Fully Isolated**: Although controlled, factors like temperature and humidity variations may still influence instrument performance subtly.
- **Operator Influence**: Human error or differences in skill among operators can introduce variability, which may not be entirely quantifiable in a short internship period.
- **Sample Size Limitation**: A larger dataset would provide more robust MU calculations. The current project was limited to selected samples due to time and resource constraints.
- **Instrumentation Constraints**: Use of different brands and models of equipment introduces variability. Ideally, a single, well-calibrated set should be used for all measurements.

Standards Compliance

All testing procedures and uncertainty estimations were performed in accordance with **IS/ISO/IEC 17025** guidelines, which govern the competence of testing and calibration laboratories. The methods used were validated and followed industry-recognized protocols to ensure repeatability, reproducibility, and traceability of the data. The calculated measurement uncertainties help establish the confidence level in reported results and are critical for decision-making in both manufacturing and construction sectors.

References and Test Report

1. **IS 1786:2008** – *High Strength Deformed Steel Bars and Wires for Concrete Reinforcement – Specification* (Bureau of Indian Standards, New Delhi).
2. **IS 2062:2011** – *Hot Rolled Medium and High Tensile Structural Steel – Specification* (Bureau of Indian Standards, New Delhi).
3. **IS 1608 (Part 1): 2018** – *Metallic Materials – Tensile Testing – Part 1: Method of Test at Room Temperature* (Bureau of Indian Standards, New Delhi).
4. **IS 808:1989** – *Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections* (Bureau of Indian Standards, New Delhi).
5. **IS 1852:1985** – *Rolling and Cutting Tolerances for Hot Rolled Steel Products* (Bureau of Indian Standards, New Delhi).
6. **Jordan, J. P.** – *A Study on the Evaluation and Reduction of Measurement Uncertainty in Mechanical Testing of Metals*, Journal of Testing and Evaluation, ASTM International, [Insert year if known].
7. **NABL 141:2022** – *Guidelines for Estimation and Expression of Measurement Uncertainty* (National Accreditation Board for Testing and Calibration Laboratories, India).
8. **Google Search (2025)** – Quick references and definitions accessed from various reliable sources such as NIST.gov, ASTM.org, and scholarly databases for clarification on statistical and engineering terminologies.
9. **Guide to the Expression of Uncertainty in Measurement (GUM)** – *JCGM 100:2008*, Joint Committee for Guides in Metrology (BIPM, ISO, IEC, IFCC, ILAC, IUPAC, IUPAP, OIML).
10. **Statistics Handbook** – *Basic Statistics for Engineering and Science*, [Insert author if available], used for understanding standard deviation, coverage factor (k), and uncertainty propagation.