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HIMALAYAN SURVEY

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BETWEEN 1982 AND 1985 SOLDIERS from the Military Survey branch of the Royal Engineers undertook a major project in Nepal. The aim was to establish a first order geodetic network—a series of precisely coordinated trigonometrical points across the whole country—on which future lower order surveys and mapping could be based. The project, which was called Exercise High Trig, was carried out in conjunction with the Nepal Survey Department. This account of the project is preceded by a brief description of the country and its people.

Topography and climate

Nepal is an independent kingdom which lies along the southern slopes of the Himalayas. It is about 900 kilometres from east to west and between 150 and 250 kilometres from north to south—about the size of England and Scotland together. It is bounded by India to the east, south and west and the Tibet region of China to the north. Its latitude is similar to that of Florida and the Sahara Desert. Topographically it divides into three distinct regions running laterally across the country. In the south is the Terai, in the centre is the hill country and to the north are the high Himalayas.

The Terai is flat and fertile and is only a few hundred metres above sea level. It is part of the Ganges Plain and shares the extreme heat of India. The hill country varies in height from about two to three thousand metres above sea level. It is criss-crossed by the lower ranges of the Himalayas and by swift-flowing mountain rivers. The majority of the population lives in this temperate region which enjoys an Alpine climate. It is heavily forested at the lower levels but the hills become bare above 3000 metres. The high Himalayas along the border with Tibet are the world's highest mountains and include Mount Everest. The climate here is arctic and the population minimal.

Kathmandu, the capital is in the central region. It lies in a flat-bottomed valley at about 1370 metres above sea level, completely surrounded by mountains. Access to the valley is not easy and it was only in recent years that a road south to India was completed. Outside the Kathmandu valley travel in Nepal is still extremely difficult and takes place mainly on foot. There is only one significant road, the East–West Highway, and even this is not surfaced in the west. The few other roads which do exist are mainly confined to the Terai, and many of these are closed for part of each year owing to the monsoons. As a result of the difficulties of travel in much of Nepal, Kathmandu has developed at a much faster rate than the rest of the country and life in the hills is still very isolated and primitive.

Culture and history

The population of Nepal is about 15 million (1981 census). The people are mainly descendants of three groups of migrants into the country—from India, Tibet and central Asia. Religion is central to the people's existence and Hinduism and Buddhism flourish side by side, with many people worshipping the deities of both.

Civilization has flourished in the Kathmandu Valley since well before the birth of Christ. The present Kingdom of Nepal was founded in the eighteenth century from a number of smaller mountain states. However, it is only since becoming a democracy in 1951, that the country has been open to foreigners to any extent. In 1962 four thousand tourists visited Nepal, in 1985 an estimated three hundred thousand did so. As a result the country is being catapulted very rapidly into the twentieth century. At present it is a curious mixture of both medieval and modern.

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Military survey involvement

Prior to 1945 there was virtually no survey control or mapping in the country. During the 1950s and 1960s the Survey of India produced a series of 1 inch to 1 mile scale maps and established some horizontal and vertical control on which to base them. Since then a number of other surveys have been done, but mostly of limited areas in support of specific projects. As a result, although there was a fair amount of survey control by the late 1970s, particularly in Central and Eastern Nepal, this was mainly in the Terai and was by no means the comprehensive geodetic network needed to support modern mapping, engineering and development needs.

In 1979 the governments of the United Kingdom and Nepal agreed that a team of British Military Surveyors would establish a network of survey control points across the length of Nepal using Doppler Satellite Positioning techniques. It was agreed that at the same time the team would make gravity observations. The work was carried out in 1980 and 1981 by 512 Specialist Team Royal Engineers who have been involved in satellite positioning work worldwide since 1963. A total of 14 Doppler points were fixed. Some were colocated with existing stations, especially those established by Czechoslovak teams during the 1970s, whilst the remainder were in places where no control had previously existed. From this followed a further agreement with the Nepalese Government to provide a comprehensive network of primary geodetic control based on the Doppler work. At the same time additional gravity observations would be made. This agreement was signed in 1982 and ratified annually until the task was completed in 1985.

The fieldwork was undertaken by 19 Topographic Squadron of 42 Survey Engineer Regiment in conjunction with the Nepal Survey Department and the final results were computed in the United Kingdom by the Mapping and Charting Establishment of the Royal Engineers.

The task

The technical requirement was to link the widely spaced satellite-determined points together and to measure the coordinates of many other points relative to the satellite points.

The accuracy that we hoped to achieve was less than 10 cm horizontally and less than 50 cm in height at all points. The 12 satellite points were linked by distance measurements, but because of the distances involved none of the points were intervisible so we had to establish intermediate points on hill tops. The position of each of these hill-top stations was determined by triangulation. Both the distances between the points and the horizontal and vertical angles were measured so that as the work progressed a network of observations connecting the survey stations was built up.

Year by year The weather precluded deployment and fieldwork during the monsoon season between April and August, so the project had to take place in the winter months. In September each year a team of about 30 soldiers deployed from Barton Stacey, near Andover, to Nepal and returned to the United Kingdom in March the following year.

In the first year work started in the east of the country with the project headquarters situated in the British Gurkha cantonment at Dharan. A total of 16 survey stations were occupied in the first year and the distances and angles between them were measured as shown in Figure 1. As the initial deployment, this was very much the 'pathfinder' for its two successors. As a result work was carried out at a steady, controlled rate, while great efforts were made to establish contacts and formulate procedures appropriate to the conditions.

In the second year, work continued westward through the central region. The headquarters was now located in Maya House, Kathmandu, fairly palatial accommodation hired through the British Embassy. Eventually this was supplemented by a tented advance camp at Pokhara in the Annapurna region. We capitalized on the groundwork of the previous year, and blessed by excellent weather, progress was rapid and more work was achieved than expected. In all 36 survey stations were occupied,

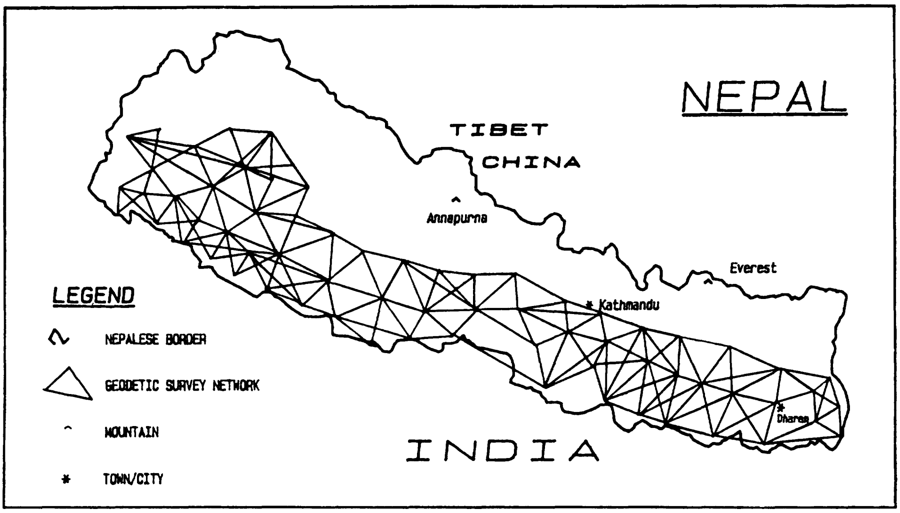


Fig. 1 The Geodetic Survey Network in Nepal

four of these being re-occupations of the previous year's stations in order to tie together the two pieces of work.

The project was completed during the 1984/85 season, finishing in the 'far west' of the country. At this time we had to work at very high altitudes—up to 5200 metres. Even compared with the rest of Nepal the hill areas of the 'far west' are remote and very primitive. Few Nepalese, other than local tribesmen, ever go there and certainly in many cases our surveyors were the first Europeans the villagers had ever seen. Because of the remote nature of the area it was necessary to locate our headquarters, once again, in Maya House, Kathmandu, where communications and services were readily available. However, with the base camp separated from the actual work area by more than 320 kilometres we had to maintain three semi-permanent tented advance camps at airstrips in the 'far west'. Two of these were in the Terai and were accessible by road, while the third lay in the hills at 2438 metres, and was only accessible by light aircraft. A total of 33 points were occupied in this final year, and several of the field parties spent an unbroken five months living in the field. Over the three years a total of 68 trigonometrical points were occupied.

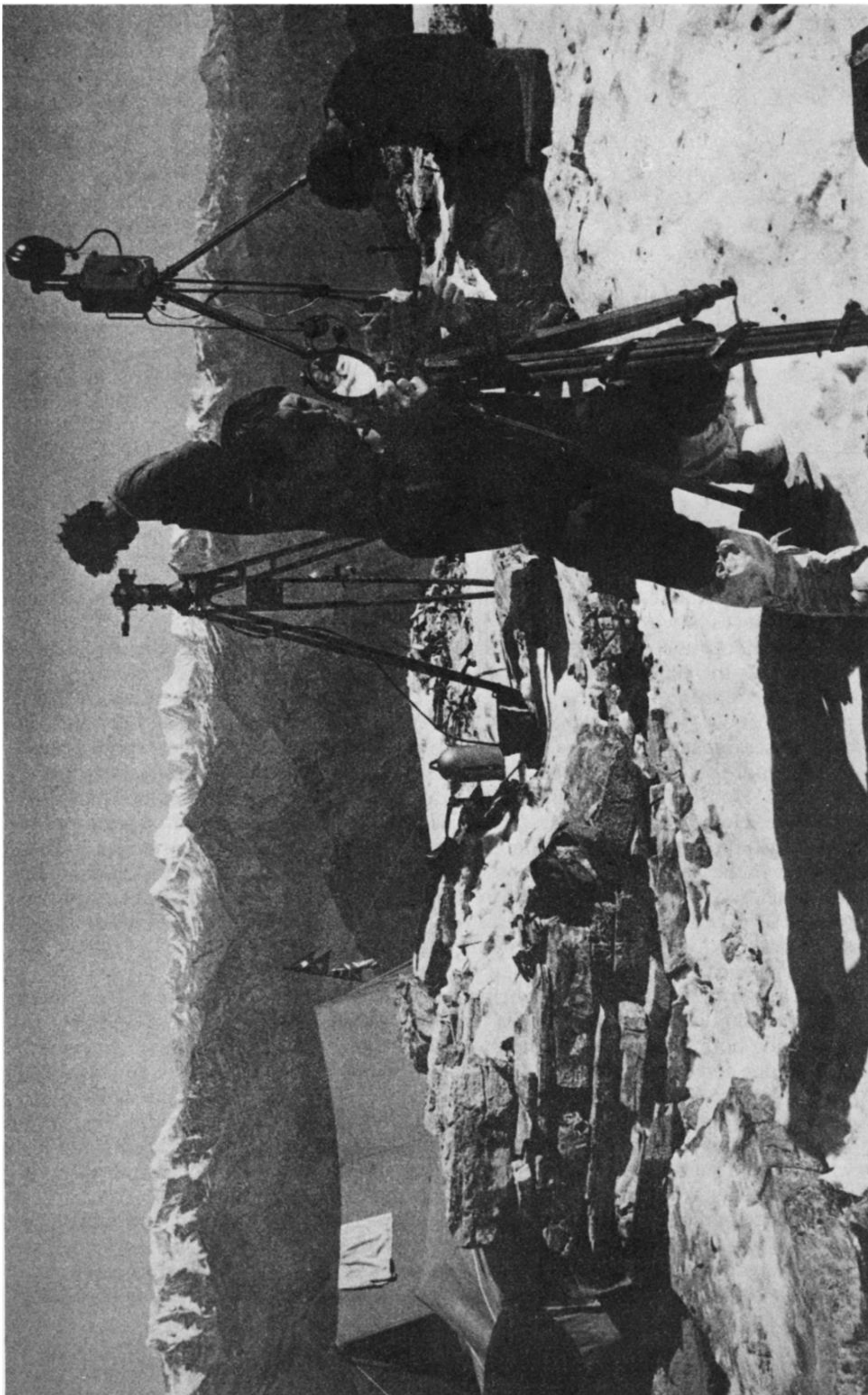
Obviously in a triangulation scheme with angles and distances such as this, three angles or three distances would fix the shape of any given triangle. Therefore, by measuring both angles and distances we were incorporating redundancies. However, lack of time and bad weather ruled out many observations. It also transpired that not all adjacent points were intervisible. By analysing the proposed network prior to arriving in Nepal we optimized the number and type of observations for the required accuracy. Eventually the values of all the successful measurements were fed into a computer which used a least squares adjustment process, allocating different weights to different measurements, to provide a final list of coordinates and heights.

So far, the points in the network were all fixed relative to each other. The network as a whole now needed orienting and positioning absolutely on the earth's surface. This was achieved by two means. Firstly by the satellite fixed points observed earlier and secondly by astronomy. Observations for azimuth, latitude and longitude were made at intervals throughout the scheme.

Work on a survey station

So much for the theoretical side, but what were the practical requirements for a field party on station? Horizontal angles between stations were measured using a theodolite.

PLATE I



Sgt Mick Barnes, L-Cpl Jock Donnan and Spr Bob Taylor observing at Bilaspyr Hiuchuli

This instrument was also used to measure the vertical angle between stations. This value, combined with the distance between the stations, was then used to derive the difference in height between the two points.

Distances were measured using a microwave instrument. This instrument comprises a master and a remote. The master at one station transmits electro-magnetic pulses to a remote set on the other station. The remote reflects the pulse straight back and, by recording the time elapsed since transmission, the master is able to translate this into a distance measurement.

Intervisibility between the mountain stations was rarely a problem as the air above 3000 metres was generally clear. However, the view from the hill stations to the low-lying areas of the Indian Plain was often obscured by a layer of cloud making theodolite observations difficult. An additional problem in the flat Terai region was that the ground height never varied by more than 15 to 30 metres. Therefore, lines of sight over distances longer than 5 to 10 kilometres, soon became obscured by trees and buildings owing to the curvature of the earth. For this reason it was decided to use a string of tall microwave communication towers that had been recently constructed by the Nepal Telephone Company. The tops of the towers were fixed in position by distance measurements from the hills. It was not possible to make theodolite observations from the tops of the towers as these were not sufficiently stable. In fact, in a strong wind they were hardly stable enough to hang on to!

The optimum times of day for different types of observations should please any time and motion expert! Horizontal angles are ideally measured at night, just before dawn, or just after dark to minimize the effects of refraction. Lights are therefore required to observe at night. On a clear night in Nepal we had no difficulty seeing the lights over 70 kilometres away. Distances should be measured once in the early morning, once in the late afternoon and once at night and the three values averaged. Finally, vertical angles should be measured between ten o'clock in the morning and midday. Although a light sometimes provided an adequate target during the day, a helio mirror reflecting the sun towards the observer was found to be more useful, operating effectively over distances in excess of 35 kilometres

Any spare time at night was spent taking observations to the stars and in case boredom set in during the day there were always plenty of technical housekeeping tasks to keep the survey team occupied. For example: one day air photography will be flown and it will be from these air photographs that future maps will be made. The individual trigonometrical points will be used to coordinate accurately points on the photographs, thus controlling their exact positioning. Therefore, it must be possible to identify each trigonometrical point on the photographs. So, shallow trenches were dug in the shape of a cross with the point at the centre. These trenches were then filled with rocks to provide a contrast against the grassy background. Witness marks needed to be selected and recorded so that if anything ever happened to the actual trigonometrical point, it could be re-located by measurement from these marks. Where there was no actual pillar, a cairn was constructed over the trigonometrical point, to help identify its position in the future, while at the same time affording it protection. Finally, a 360° photographic panorama was required. This panorama was annotated with the names and magnetic bearings of all significant features, to help subsequent occupants of the station orientate themselves.

Summary of technical achievement

The last stage of the project was to analyse all the observations on return to the United Kingdom. A total of 1630 observations were taken between the 68 trigonometrical points and, with the exception of the microwave towers, the final accuracy of the trigonometrical point coordinates was well within the original specification. The microwave towers were fixed to less than a metre. One question everyone asks is, 'How high did you make Everest?' Unfortunately, our triangulation network was designed to provide countrywide coordinates and it was not intended to height Everest with any greater accuracy than several recent expeditions. What we can say, however, is that the mountain has not moved and that 29 029 ft is as good an estimate as we are likely to have for some time!

Administration

General Once the field parties reached their stations the successful completion of the technical work was rarely a problem. With up to nine field parties spread widely over such a country, it was always the administrative and logistic side of life that caused the problems. This was particularly true in the first year when it was all so very new and in the third year when the work area was so far from the headquarters in Kathmandu and, worse still, a lot of the points were above the economical helicopter ceiling, leaving teams no choice but to walk in. This method of access could take up to two weeks.

The project headquarters in Dharan and Kathmandu, successively, were in daily communication with field parties by radio. Therefore, advice on technical, medical, money or labour issues could be given instantly. However, more tangible help in the form of re-supply could take as long as three weeks to get to the field parties. In addition to problems caused by the topography and the weather, there were further constraints imposed by the variable availability of aircraft and vehicles, and indeed local labour. Of course, there was always the overiding financial limitation. Therefore, it was fundamental to the success of the operation that all re-supply and re-deployment of teams was painstakingly planned and carefully coordinated.

Transport The nature of the problem and the resourcefulness required is best illustrated by the transport used. Maximum use was made of the helicopters and light aircraft flown by the Nepalese Army Air Wing. Wherever possible helicopters dropped teams on their points, or if this was impractical they would be left as close as possible. With so few roads the success of the project relied heavily on the remarkable efforts of the pilots for whom we have much admiration. However, at the other end of the spectrum there were many times when 'Shanks' pony' was the only available option.

Between the two extremes lies the Landrover and some less conventional forms of transport, including local buses, rickshaws and ox-carts. River crossings proved interesting—in some places we were fortunate and were able to take advantage of cable ferries; in others one just had to 'trust in the Lord' and try to ford (some were luckier than others) and occasionally we had to resort to more desperate methods, namely dug-out canoes and gourds. These gourds are flotation aids about the size and shape of a football, made from hollowed-out vegetable skins. They are worn on a thong around the waist—eight of them will keep a man's head above the water. The locals took great pride in their ability to calculate the correct number of gourds required to raft a field party's equipment across the river!

Field party composition

A standard field party comprised two British surveyors—a Corporal or Lance-Corporal in charge, with a sapper assistant. However, there were times when Lance-Corporals or sappers as young as 21 were required to lead field parties—an enormous responsibility! The field parties were accompanied by a Nepalese surveyor, acting in a liason role, who worked very closely with our men and was an integral part of the team. Each party also had a three-man trekking team supplied by a Kathmandu agency. The boss, called a *Sirdar*, was an experienced and capable mountaineer. A very competent man, he would forge a firm friendship with the British soldiers for whom he worked. The Sirdar was assisted by a cook who also acted as his deputy, and a cook-boy. The team was completed by a special porter who was always hired locally. It was his duty to haul firewood and water to the survey station, often far above the tree-line and the nearest stream. These special porters were particularly hardy men.

Although this was the permanent composition of a field party, as many as sixty-five porters were required to physically move teams onto their hill tops.

A typical deployment

After arrival in Kathmandu there would ensue a frantic period for settling into the Maya House Headquarters; for the lengthy business of unpacking, and for checking that all the equipment had survived the flight and was in good working order (this is as vital for non-technical kit such as Tilly lamps as it is for theodolites). Once all the kit had been issued to field parties it was time to pack for the first deployment.

PLATE II

The farewell party at Pokhara

The flight westward by Nepalese Army aircraft was from Kathmandu along the flat expanse of the Terai to the tented advance camp at Nepalgang Airport. This advance camp, like the others, was expertly manned by soldiers from the Queen's Gurkha Engineers who were attached to the exercise. Teams were immensely grateful for their efforts as they utilized their knowledge of both Nepal and the British Army to satisfy all needs with the minimum fuss. In Kathmandu detachments had enjoyed pleasant temperatures, now they were struggling in temperatures in excess of 38°C, in a noticeably less civilized environment. The next stop was to be the advance camp at Jumla to the north, nestled amongst the mountains on the horizon; but there was a wait of four days before the party was moved completely by the tiny Skyvan aircraft. Because Jumla is at 2400 metres and has a very short airstrip, the Skyvan can only land with the minimum load, and so it took four trips per field party and these trips had to be completed early in the morning before severe thermals rising off the mountains make flying unsafe. Indeed a feature of Jumla life were the beautiful still sunny mornings followed by fierce katabatic winds sweeping down the valley in the afternoon.

A further four days wait at Jumla was necessary while sufficient porters were recruited. This provided an opportunity for sorting out the medical supplies into manageable packs and laying out the cold weather kit brought for the porters; also for purchasing the chickens and goats that were to be dragged up the mountains as meat on the hoof.

Eventually the porters arrived and immediately the ritual haggling for loads began with much cursing and shouting and lots of picking up and putting down. Such arguing may go on for an hour. All the loads were heavy, generally weighing about 27 kg, and came in the most unmanageable shapes, yet once the arguing was over, the porters walked happily for as many as nine hours a day, their pace quite unaffected by gradient. One party discovered itself six porters short, so men had to carry double loads—54 kg.

For the next fascinating 14 days the team moved up from the liberal vegetation of the river valley, to the open expanse of barren hillsides and on above the snow line to the summit at 5000 metres. Finally, after three weeks, work could start.

Different stations

Although the party described ended up well above the snow line, not all the points were the same. In fact no two survey stations are ever the same and this was particularly true in Nepal with its unique range of topography.

As has already been mentioned, in order to achieve satisfactory lines of sight in the Terai, several stations had to be located at the top of microwave towers. In the hill country field parties had to clear lines of sight through the luxuriant forest of the lower reaches. This problem did not arise in the more sparsely vegetated areas higher up, though at one point the survey team discovered that the trig pillar had been built on top of a burial ground. Their every movement was closely monitored by the gravekeeper.

Higher still, stations were set up on barren mountainsides several days walk from the nearest settlement and then of course, there were those above the snow line, and indeed those that were not, until the weather changed for the worse and altered the whole complexion of life. One party, equipped only for sub-snow line conditions, was well and truly caught when the weather deteriorated and had to spend six weeks living and working in deep snow. Eventually they had to be lifted out by a helicopter shuttle after their survey tent was struck by lightning and one of their living tents collapsed under the weight of snow.

Conclusion

We consider ourselves most fortunate to have participated in such a successful task and one which may well be the last first order triangulation of this magnitude that will need to be done. We are also most grateful for the opportunity to have seen such a fascinating country at close quarters and to meet and work with the charming people who inhabit it. In particular we are most grateful for the cooperation and assistance which we received from the Nepalese Government, especially the Nepal Survey Department and the Nepalese Army Air Wing, without whom we could not have completed the task.