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Site Selection Kalabagh Dam Project

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ABSTRACT

Kalabagh dam is a multipurpose project which shall generate 2400 MW of low cost hydroelectric power near the load centre and create additional surface storage of 7.6 MAF on river Indus. Search for a dam site near the Kalabagh Town started about 30 years back. Various Consultants e.g. Tipton and Hill, Chas T. Main, Harza and Associated Consulting Engineers identified different sites and carried out geological and soil investigations. Out of the proposed sites, A, B and C, Associated Consulting Engineers in the Feasibility report recommended site C as it was comparatively less disturbed by tectonics and offered better prospects for layout and consturction Materials. In 1980 World Bank group reviewed the feasibility report and confirmed the technical and economic suitability of site 'C'. The UNDP sponsored detailed studies for preparation of Tender drawings and documents. Kalabagh Consultants, a Joint Venture of Binnie and Partners, Harza, Preece Cardew, ACE and NESPAK started work in 1982. They reviewed the existing data and studied some more sites e.g. D, E, F and G. Finally Site P7AA close to site E and C was selected.

Alignment refinement studies continued alongwith the project layout studies. Various alternative layouts were studied with the same basic criteria. As a result of optimization, the final project would comprise of the following main features: Two independent spillways each having a capacity of about 1 M cfs on the right bank, main dam (earth and rockfill) with crest at 945 SPD, diversion channel on the left bank, 4 low level conducts and 8 power tunnels each equipped with 300 MW turbines.

The bed rock consists of alternating Swalik beds of claystone, siltstone and sandstone. At places the claystone beds were found sheared and having residual strength. Geotechnical studies indicated that it would be safe to replace the hillock containing the LLC and Power tunnels with rollcrete and then build dam over these conduits.

INTRODUCTION

The river Indus rises in Tibet at an elevation of about 18,000 ft. above sea level. After flowing through the Himalayan mountain ranges and then foothills, it debouches into the Punjab plains at the town of Kalabagh and flows further 770 miles across the plains before reaching the sea. The Kalabagh dam site is about 120 miles d/s of Tarbela Dam and 10 miles u/s of Kalabagh Town. Fig. I shows location of Kalabagh Dam Project. The dam site is connected by a metalled road and railway line passes at a distance of 8 miles from the site. The catchment area of river Indus at

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the site is 110,500 sq. miles of which the catchment of river Kabul at Nowshera is 34,300 sq. miles. The long term average annual discharge of the river Indus at the dam site is 89 MAF. Flows are highly seasonal, 84% of the discharge occurs on an average during the Kharif season and 16% during the Rabi season. The usable storage volume of Kalabagh reservoir will be 7.6 MAF. Kalabagh dam will have an ultimate installed capacity of 36000 MW. It will be operated in conjunction with Tarbela both for power and water demand. The project is expected to be completed by 1993. It would supply power closer to the load centre. It will also reduce the frequency and severity of floods in the areas downstream.

Site exploration and Soil investigation started more than thirty years back. The site and project layout plan have been selected for the tender design and drawings. At the time of writing paper, investigations are continuing for the detail design stage. The paper describes the different sites considered and the layouts of the project before selecting the final site and layout.

REQUIREMENT OF A GOOD DAM SITE

The basic requirement of a good damsite is a narrow gorge of the stream, upstream of which the valley should be wide to store enough water. The rock on which the dam and its appurtenant structure are to be laid plays an important role in the selection of site and the type of the dam. Geological aspects such as the good type of rock, strike of the beds normal to the flow and dip towards upstream and the rock to be free of wide discontinuities are requirements for a good damsite. The required construction material should be available at a reasonable haulage distance.

For an embankment dam provision of a separate spillway is necessary. A natural saddle wide enough and having elevation slightly lower than the crest of the dam is beneficial. If such conditions do not prevail the design and construction are planned in a way that the excavated material could be used directly in the dam section. Sufficient space should be available for the river diversion. The discharge and head available for the penstock are directly responsible for the production of electricity. Power House should have a good foundation. It should be located close to the load centre. Perennial flows in the river should be adequate. If the rains are concentrated during short periods a large reservoir is required to store water. The water reservoir rim should be higher than the crest of the dam. Value of property submerged and number of persons displaced should be minimum. Transport link and housing facilities should be available. All these aspects would be taken into consideration while the site selection is discussed in the following pages.

POST-TARBELA DEVELOPMENT

In order to meet the growing demand of electric power, by the turn of this century, Pakistan shall have to commission additional hydropower aggregating to 12,900 MW. This would comprise Kalabagh, and other attractive sites already identified on the Indus. In addition would be the optimum development of Mangla, Tarbela and another 300 MW from low head/small hydels and run-of-river projects.

Additional surface storage of water is also needed to meet the growing irrigation demands and also to replenish the storage lost at Tarbela due to sedimentation. In selecting the priority schemes, it is advisable to choose multipurpose storage-cum-power projects.

The most important factors which govern the selection of a project for priority development are the technical feasibility, initial investment cost, potential storage/power benefits.

Kalabagh has a definite edge over any other dam of equivalent storage in the extent of studies, investigations and volume of data collected and reviewed. Kalabagh has a larger catchment area, sources of water are diverse e.g. different types of run off (snow melt, monsoon and winter rain), Kabul, Haro and Soan rivers join Indus d/s of Tarbela.

World Bank's special group headed by Dr. Pieter Lieftinck carried out study on "Water and Power Resources of West Pakistan". The study concluded that in the various options of developments, Kalabagh should be the first major post-Tarbela project to be commissioned by 1992.

KALABAGH DAM PROJECT FUNCTIONS

Kalabagh Dam Project is proposed to be constructed at one of the last downstream location on Indus River before it enters into the plains. It is planned to be multipurpose with the following important functions:

a. To generate a large amount of low cost hydroelectric power energy – in conjunction with Tarbela – near major load centres and supply the existing grid for meeting the growing power demand of agricultural industrial and domestic consumers.

b. To create additional surface storage on the Indus, thus providing better system control and management for supplying assured, adequate and timely water for the crops.

c. To regulate and control the flood peaks of the Indus to minimize the flood hazards downstream.

d. To replace the lost live storage capacity of Tarbela, Mangla and Chashma reservoir which are being gradually depleted due to sedimentation.

e. To extend irrigation facilities to new areas.

INVESTIGATIONS

In 1952, the Government of Pakistan created a Dam Investigation Cell (DIC) which carried out reconnaisance level studies and identified a number of dam sites on the Indus and its tributaries. DIC identified a dam site in the Kalabagh gorge and carried out initial sutides. Subsequently, other agencies like Tipton and Hills, Chas T. Main (Lieftinck Group) and ACE were also engaged. Fig. 2 shows location of different sites studied for the project.

STUDY BY TIPTON AND HILL

M/s. Tipton and Hill (T&H) of USA were engaged in 1954 to explore Indus river gorge upstream of Kalabagh Town for a suitable dam site. They submitted feasibility report of the project in 1956, for a location here-in-after called site 'B'. their report indicated that reservoir higher than elevation 925 feet encroaches Peshawar Valley and hence should not be attempted, while Nowshera will have to be protected by raising bunds on. Kabul river in keeping with the reservoir levels.

STUDY BY CHAS T. MAIN

Chas T. Main (CTM) of USA were engaged by Lieftinck, World Bank Group, for their Sectoral Planning Study of mid 1960's. As part of assignment on surface storage, CTM appraised T&H proposal of 1959. They developed a proposal for Kalabagh Dam on the same site and capacity as proposed by T&H and submitted their report in 1966. By that time, some sediment inflow data for Indus river had also become available. They proposed sluices at the bed level alongwith a spillway of 2.6 million cusecs on their top.

STUDY BY WAPDA/HARZINT

WAPDA in collaboration with Harza Engineering Company International(HARZINT) of Chicago, USA investigated a site further downstream where the bed rock(sandstone) was much stronger than anywhere else in the gorge. For this reason a concrete gravity dam was contemplated. Investigation on this location, designated as site A, were carried out during 1968-72.

FEASIBILITY STUDY BY ASSOCIATED CONSULTING ENGINEERS

Associated Consulting Engineers (ACE) Ltd., were engaged by WAPDA in 1972 to undertake feasibility study of the Kalabagh Dam Project. In the vicinity of previously investigated location, ACE identified two other potential sites for the dam and designated them as C&D. Site C was located immediately downstream of the confluence of Indus and Soan rivers, while site D was just upstream of the confluence. Site D envisaged two reservoir schemes, one each on Indus and Soan rivers.

ACE completed technical evaluation of the four sites including comparative cost. Based on this, ACE recommended site C with same height of the dam and sluicing arrangement as conceived by T&H and CTM. During May-June, 1980, a detailed review of the existing data and reports was made by a team of the World Bank which confirmed that site C was technically and economically suitable. The four sites are described as here under.

SITE 'A'

Site 'A' is about 5 miles upstream of Kalabagh Town. The river channel at this site flows through a narrow george, about 1,000 ft. wide with topography best suited for building a concrete gravity dam.

GEOLOGY AND FOUNDATION SITE 'A'

Fig. 3 shows the geologic plan at the dam site while Fig. 4 gives the section along dam axis. The bed rock at the abutment and foundations consists of massive beds of sandstone interbedded with sheared clay-shales and siltstones. The angles of dip vary from 38^o to 18^o across the river. The depth of gravel in the river bed is about 120 ft. The sandstone bedrock at this site is hard and massive but it has been subjected to major tectonic disturbances. The site lies within the range of undoubtedly established fault zones of major acitivity. In fact the site is crossed by two major fault zones, each upto 200 ft. wide and also traversed by 3 faults crossing the river at the damsite and 6 other faults running along the valley. Fig 5 shows the regional geology of the area. The diversion tunnels would have to be excavated through the major fault zones and their downstream end would emerge at the base of a 1500 ft. high cliff. The construction and slope stability problems would be formidable.

ADEQUACY OF CONSTRUCTION MATERIAL SITE A

It was proposed that the structures including the dam would be concrete (about 20 million cu.yds). The main construction material required at this site would be concrete aggregate. The sandstones would not make adequate aggregate when crushed. Therefore the material obtained from foundation excavations (about 85 million cu.yds) would be mostly wasted. A sand and gravel quarry existed at Mari Indus, about 8 to 10 miles downstream, and there is a limestone quarry at Jabba Hill, 10 to 12 miles from the site.

PROJECT LAYOUT AT SITE A

The choice of layout of the project components is rather limited at the site because of the small working space available. The principal features of the layout are that diversion tunnels would be provided at the right flank and power tunnels on the left flank. The sluiceway/spillway would be provided in the main gravity structure. Since the slope of the bedding is very steep, the foundations would have to straddle alternating beds of sandstone and claystone. This would require elaborate foundation treatment to make the foundation suitable for high concrete structure. The design of the overflow section of the dam (sluiceway) must take into account the dissipation of considerable hydraulic energy for which a massive concrete stilling basin would have to be constructed on rather unfavourable geologic conditions.

SITE 'B'

Site 'B' is located about 2½ miles upstream of site 'A' and about 4½ miles downstream of confluence of rivers Soan and Indus. Construction of an earth embankment has been considered at this site. Due to rather high banks on either side, the space for the location of appurtenant structures is restricted.

GEOLOGY AND FOUNDATION SITE 'B'

Fig. 6 gives the geology of the site and Fig.7 shows the section along dam axis. The rock under the dam comprises sandstone, shales and siltstones. The sandstones are softer than at Site 'A'. There is only one thick bed of sandstone and even that only extends over a part of the site. Bedding shear were noticed in the clay beds. The dip of the beds, about 13^{o} coupled with thin beds would make it impossible to site all major concrete structures on an adequate thickness of sandstone. In order to prepare adequate acceptable foundations for these structures, large excavations will be required. Fifteen faults have been identified in the site area. Some of these faults have displaced the strata by 50 to 100 ft. A fault has been identified on the left bank which can be traced for a distance of 3 miles in SW direction. The faults are spread over the site in all directions and it would be impossible to position the structure so as to avoid them entirely. The faults would also make tunnelling hazardous. The depth of river graval is about 100 ft.

ADEQUACY OF CONSTRUCTION MATERIALS AT SITE B

The required exvacations would yiled mainly sandstone, shale and siltstone. These would probably be adequate for the bulk of the shoulders and for the core of an earth dam, but it might be difficult to separate the material because of the thin bedding and the dip. Sands and gravels for filters, drains and aggregate would have to be obtained from borrow areas in nalas or in the terrace gravels near Site 'C' some distance away. Processing and crushing would be required to obtain the correct grading.. Rip-rap would have to be borrowed, possibly from the Jabba limestone quarry.

PROJECT LAYOUTS AT SITE B

The project layout envisages the location of the diversion cut and the sluiceway structure an the auxiliary spillway, on the left flank while the power tunnels would be located on the right flank. (Fig. 8). Because of the limited space available, the choice of location of the structures is restricted. Some alternative layouts can be worked out to accomodate another spillway. However, the restrainst due to difficult topography and unfavourable geological conditions leave rather limited choice.

SITE 'C'

Site 'C' is situated just d/s of the confluence of the rivers Indus and Soan. the river channel at this site is wider than at 'A' and 'B' and the flanks on either side are comparatively lower and allow for better siting of earth embankment and appurtnant structure.

GEOLOGY AND FOUNDATIONS SITE 'C'

The site is underlain by soft sandstones. However, there are three massive beds of sandstone, each with thickness of over 100 ft. The general dip angle is only 3^{o} to 4^{o}. There are also hard clay and siltstone strata. Some shear lenses were found but so far no highly developed bedding slip surfaces have been noticed. Compared to Site 'B', the overall percentage of sandstone is much greater than clay-shale and siltstone. The massive character of these sandstone beds with practically, no joints and near horizontal bedding makes possible the siting of all the major structures so that each is founded entirely on a single bed of sandstone with adequate cover over the claystone and siltstone. Two faults of small displacements, have been detected. The depth of gravel in the river bed is about 100 ft. The right flank is formed of deep terrace and fan deposits mainly sandy gravel with some layers, the maximum depth of these gravel deposits is about 160 feet. In the lower terrace, there are also areas of silt overlying the other deposits. The proposed dam axis is located about 8 miles from the Kalabagh fault and about 17 miles from the Bannu fault. Rock motions on this site due to an earthquake originating on the Kalabagh fault would be less than those at Site 'A' or Site 'B'.

ADEQUACY OF CONSTRUCTION MATERIAL AT SITE 'C'

The quantities of sandstone and sandy-gravels which would become available from the required excavations would be more than adequate for the shoulders of the embankments. Sand and gravels for filters, drains and concrete aggregate will require crushing. The silt deposits are unlikely to be suitable for incorporation in the dam. If so, there would be a need to borrow material for the core. It is doubtful that the Contractor could easily separate the relatively thin clay shales and siltstones from the sandstone layers. Potential borrow areas for clay have to be investigated, but adequate sources are thought to be available. Haul distance of 10 miles or more may be required. Rip-rap would probably be obtained from the Jabba limestone quarry.

PROJECT LAYOUTS AT SITE 'C'

Fig. 9 shows the location plan of Site 'C'. Site. 'C' offers more flexibility of siting various components of the scheme, than Site 'A' and 'B'. According to the laboratory and insitu tests performed, the foundation sandstone appears competent to carry moderate loads with acceptable deformation when in a confined state. However, the sandstone may be susceptible to internal erosion or piping when subjected to high hydraulic gradients. Such considerations may preclude the possiblity of provision of a combined diversion-sluiceway structrue and the previously proposed high structures for the power house. Various alternative layouts to reduce foundation loading and to avoid high concrete water retaining structures were studied. These included the provision of a separate diversion structure and tunnels for power, sluicing and diversion. Further, it is extremely important that the chute and basins of sluiceway/spillways structures should be easily accessible for inspection and repair. This consideration may lead to provision of two service spillways. The final layouts will be developed after detailed engineering study. However, the preliminary exercise shows that Site 'C' offers sufficient flexibility to accomodate modifications of the kinds mentioned above if they are adopted after further studies.

SITE 'D'

The site is located about 0.5 miles upstream of Site 'C', just upstream of the confluence of rivers Indus and Soan. The valleys of both the rivers are fairly wide here and offer wide working space and flexibility of location of the structures. At this site two main embankments would be constructed, one on the Indus, the other at Soan with a rock 'nose' in between. Thus two reservoirs would be created which would be linked by a channel excavated through the nose.

GEOLOGY AND FOUNDATION SITE 'D'

The geology appears similar to that at Site 'C' which is only about 0.5 miles downstream. There has been very little investigation carried out at this site. The available information is mainly based on exposures of strata on the cliffs and a few boreholes. Some faults have been mapped in the nose between Indus and Soan. One fault shows a horizontal displacement of about 50 ft. The 'nose' may turn out to be a weak divide between the two embankments.

ADEQUACY OF CONSTRUCTION MATERIAL

Although the balance between sandstone and sandy gravel in the required excavation would be slightly different to that at Site 'C', there would be adequate material for the shoulders of the embankments. In other respects, the situation regarding construction materials would be same as at Site 'C'.

PROJECT LAYOUTS AT SITE 'D'

The layout conceived at the feasibility stage consisted of a sluiceway with a discharge capacity of one million cusecs located in the 'nose' between the two rivers. A spillway of 1.5 million cusecs capacity was proposed at the right flank making the total discharge capacity of the reservoir as 2.5 million cusecs. The power channel with tunnels and power station were located on the left flank. Fig. 10 shows the location plan. An important characteristic which the site could offer is the possible creation of two independent reservoirs, for wider range of release options. The flow through a connecting channel between the two reservoirs could be controlled by providing a high buttress structure. By closing the gates when the reservoirs were full it would be possible to retain the water in Soan reservoir at a higher level, independent of the operation of the Indus reservoir. The availability of high water head in Soan could be utilized for additional power production. However, the total inflow from Soan is very small and the withdrawal of water through generation would deplete the level in a few weeks time. Thus the advantage gained through provision of two reservoirs would not be significant.

STUDY BY KALABAGH CONSULTANTS (KC)

Following World Bank's appraisal of 1980, UNDP expressed its willingness to sponsor a detailed study leading to preparation of tender documents. Consequently, in February, 1982, Kalabagh Consultants (KC) a joint venture of five consulting engineering firms comprising of Binnie, Harza, Preece Cardew, ACE and NESPAK were appointed to undertake an engineering study for preparing a fully developed project proposal. As already indicated, four sites – designated as A, B, C and D had been investigated prior to appointment of KC. Therefore,Consultant's responsibility included carrying out a review of existing sites including the feasibility report of site C prepared by ACE. Additional subsoil information which was now available included 190 boreholes with a total length of 31000 ft., 270 pits, 50 trenches and 4 adits. Fig. 11 shows the subsoil exploration plan. Though initial choice of KC was also for site C recommended by ACE, the Consultants reviewed the features in the light of the advice of their geotechnical expert Prof. Skempton "not to construct structures to retain water head above 160 feet". This brought about a major change in the concept and search for several other alignments in the vicinity of site C, was undertaken.

PROGRESSIVE DEVELOPMENT OF PROPOSED LAYOUT

a) Development of the project layout is the most important factor in planning a large multi-purpose scheme such as Kalabagh. It is not a matter that can be decided at the start of the study because all other aspects of the study may have an influence on the choice of layout. Studies of alternative layouts are, therefore, undertaken concurrently with the other facets of the overall project study, so that the adopted layout evolves as the results of the hydrologicai, geotechnical, economic and other studies become known.

b) The project site is selected in the area where there is no congestion and the structures are well separated from each other for ease of construction and maintenance.

c) It also allows space for modifications at any time if conditions are found to vary from those assumed at the project planning stage. There is enough space to allow the safe diversion of the river of Indus size.

ALIGNMENT REFINEMENTS

a) Despite initial preference for site C, there were other locations a short distance downstream where topography appeared to be more favourable. These locations were designated as E and F and shown in Fig. 12 and 13 respectively. At each location various arrangements of the main structure viz spillways, diversion channel, power features and low level outlet works were laid out and evaluated.

b) Sensitivity tests were carried out, covering retention level in the reservoir, installed generating plan capacity and sluicing regime to check whether such changes could affect the choice of site.

c) For a single reservoir scheme, the choice was primarily limited to alignments C and E. However, in view of the potential savings in cost due to reduced excavation and Consultant's conclusions that the foundations can be made satisfactory it was considered that site E would be better location for a single reservior scheme.

d) Alignment E had the following technical advantages:

   i) Steep escarpment carved out by Sanhi nallah on the left bank of Indus. Sanhi nallah offered a satisfactory location for the power station, avoiding deep excavations.

   ii) A bend in the Indus, a short distance downstream of the dam axis, offered the opportunity of reducing the lengths of outlet channels and tail races.

   iii) There is less overburden on the right bank and the ground rises more steeply than that of site C therefore the length of dam and works required for cut-offs would be less.

In order to evaluate technical and economic features of various proposals, a number of variations of dam axis and structure layouts were developed and evaluated. Alignment CE-II (a combination of axis C and E) with one spillway located on the left bank and one on the right bank was considered.

In order to avoid buried channel under the spillway on left bank, alternative layout such as P4, P5 and P6 were studied but they did not provide satisfactory solution. Therefore alternate layout P7A with both the spillways on the right bank was developed. Layout P7B in which the diversion channel was located between orifice spillway and the Indus river on the right bank was also considered. Finally layout P7AA as shown on Fig. 14 was selected based on balanced engineering judgement comparing the advantages of different layouts, with consideration given to diversion and construction features, scheduling and post constuction maintenance. The project layout optimization study was influenced by two major factors i.e. (i) place the spillway head-works where adequate sandstone foundation (atleast 40 ft. thick) is available and (ii) reduce the excavation quantities as far possible.

The selected layout (Fig. 14) comprises of an overflow spillway and an orifice spillway along-with right wing dyke and right auxiliary dam on the right bank. The structures avoid the Kharjwan fault. Main dam spans from orifice spillway to diversion channel of the left bank. The diversion channel shall be plugged by the closure dam. Then come the four low level outlet tunnels and eight power tunnels topped by an embankment on the left bank. In order to improve stability, it was decided to replace the rocks enclosing the tunnels by rollcrete, thereby forming the conduits.

MERITS OF SELECTED SITE

1. There is no congestion or interference of structures on either bank.

2. Access to the power house is easy during as well as after construction.

3. There is relatively more flexibility for adjustment to project layout and there is no adverse bend.

4. Both the spillway are founded on adequately massive sandstone (more than 40 ft) and involve limited excavations. The excavation is the least in this alignment.

5. The diversion channel on the left bank is so located that access to it is available without having to wait for construction of an access road to the right bank.

6. Route of transmission lines from power house to switchyard is most convenient.

7. The structures are not subjected to head of water more than 160 ft.

8. No concrete structure is located on the fault.

9. The power house being located u/s of escarpment of Sanhi nallah, the excavation is less.

GEOTECHNICAL ASPECTS OF SELECTED SITE

Fig. 15 is the geological plan of the selected dam site while Fig. 16 gives section through the dam axis. For progressive evolution of layout at the proposed project site, the orientation of beds and their engineering properties have played an important role. Bed rock found at or near the site belong to Dhok Pathan which falls in the upper part of middle Siwaliks, of middle Miocene age. The rocks are described as under:

Sandstone: t is the predominant rock which has been divided into four categories of SS-1 to SS-4 on the basis of hardness. SS-4 is the softest and constitutes upto 90% of the rock unit. These are soft and composed uniformly of fine sand and nonplastic silt particles 5% to 34% and upto 13% clay particles. These are mostly composed of angular to sub-angular fragments of quartz with part of the cementing material of silts and clays. Occasional hard ribs with calcium carbonates as cementing material are also present. Samples when placed in water disintegrate. Joint spacing is from 5 to 30 feet which are tight or filled with calcium carbobate. Irregular stress relief joints are common on exposed surfaces. The tests have revealed angle of internal friction ϕ between 30^o and 46^o (adopted 38^o), effective cohesion (C) between 2100 to 4300 PSF and elastic moduli between 65,400 and 458,000 PSI. Bearing pressure of 8 tons/sq. ft. has been adopted. 50% of the field permeability tests have given the values of less than 2 Lugeon (2×10^{-5} cm/sec).

Clay-stone/Siltstone: Clay-stone comprises over-consolidated silty clays, comparatively hard and laminated at places. Contain some calcium carbonate and when placed in water, the clays gradually slake after drying out. Siltstone is also hard and is clayey silt to sandy silt. It is commonly found at the base of sand-stone beds or within the claystone. High angle joints occur more frequently than in sand-stone. The bed contains a variety of shear features i.e thrust joints, oblique shears, flattened shear lenses and fully developed bedding shears, .he values are 14^o, 12^o and 10^o respectively). Shear box tests on intact specimens have given a peak value of C' = 4.5 PSI and ϕ as 23^o. As the claystone is mostly sheared along bedding plane, :. finally adopted values are $\phi = 12^o$ along bedding and $O = 22^o$ across bedding.

Gravel Beds: Occasional thin gravel beds occur within or at the base of a few of the sandstone beds. The beds can vary in thickness from 2 to 5 feet or more, and consist of sandy, sub-rounded to rounded gravels size varying from 1/4" to 3". Part of the beds are slightly cemented but the proportion of sand can vary. No satisfactory undisturbed samples could be obtained, however where exposed it appears dense. The shear strength has been assumed to be that of a compact cohesionless sand.

BASIC CRITERIA FOR PROJECT LAYOUT

For project layout some basic criteria were evolved based on studies and expert advice.These criteria, as outlined below, were kept in view while evaluating various alignments:

a) Maximum reservoir retention level would be 925 feet with drawdown to elevation 825 having a utilizable storage capacity of 7.6 MAF.

b) Peak inflow of 3.5 M cusecs at maximum retention level of 925 feet would be routed through the reservoir at elevation 937 feet with outflow limited to 2.2 M cusecs.

c) A total capacity of 2.0 M cusecs would be provided through an orifice type spillway and a gated overflow spillway.

d) 4–LLC for second stage diversion will be required. 2-to be converted to power and 2-to be retained for emergency drawdonw till confidence gained, and then converted to power.

e) The ultimate hydro-electric plant capacity would be 3600 MW comprising 12X300 MW unit.

f) Water retaining concrete structures such as spillway headworks would be designed and located so that they would not retain more than 160 feet head of water and would not be founded on less than 40 feet thick sandstone.

g) Unfinished diameter of any conduit would not exceed 42 feet. The distance between centreline of conduits should not be less than two excavated diameters and cover over the conduits should not be less than tunnel's excavated diameters. The power conduits and low level outlets shall be conduits through Rollcrete.

h) The dam would have U/s slope of 1:2.5 and D/S slope 1:2 and would have a central imprevious core taken down to the bed-rock.

i) Roll-crete shall be used in foundations as a substitute for in-situ weak rock beds under power dam, intake embankment dam and wherever required.

j) No concrete structure shall be built on Kharjwan fault in the dam vicinity.

k) The power station should be located so that large rebound movements due to deep excavations should be avoided if possible.

MAIN FEATURES OF PROJECT

The main features of the project are:

Main Dam: The dam would consist of rolled earth and rock fill embankment. The core would be built of-claystone while the shoulders that of rolled sandstone. The entire material would be obtained from the excavation of structures and the diversion channel. The clay core shall be taken down to the bed rock to form a positive cut off. Chimney drain will be provided at the back of the core. A typical cross section of the dam is shown in Fig.17. A free draining compacted washed river gravel zone has been incorporated in the u/s shell. The dam slopes at 1 in 2.5 on u/s and 1 in 2 on d/s. The crest is at elevation 945 and length at crest is about 6000 ft. Free board is 20 ft. The embankment shall be designed against rapid drawdown and an earthquake of 0.19 g.

Dame Section over Power Tunnels and LLC: In the Project Planning Report, the Consultants had designed 36 ft. diameter tunnels through the bed rock beneath the low level outlet dam and Power dams. After discussions with Panel of Experts, it was decided that in order to increase the stability of the dams containing the Power tunnels and LLC, the rock shall be replaced by rollcrete and the conduits excavated through it. Fig. 18 and 19 show the typical cross sections of dams over the low level outlet works and Power tunnels. The clay beds shall be excavated upto sandstone bed 7. A continuous slab about 70 ft. thick of rollcrete shall be constructed. Sand shall be placed at the location of tunnels which shall be excavated later on to. form tunnels through the slab. The area under the core shall be reinforced concrete. The embankment is similar to main embankment with central clay core and u/s and d/s rolled sandstone shells. The height of the emnbankments would be of the order of 200 ft.

Spillways: Instead of one big spillway, two dissimilar spillways with different operating ranges and discharge characteristics have safety and operational advantages. Therefore it was decided to have two separate spillways each with a capacity of about 1 million cfs. at RL-930 One of these is an overflow spillway and the other orifice spillway.

Overflow Spillway: The overflow spillway has a low gravity overflow section and is located in the west of the Kharjwan fault. During PMF, it will discharge 1.2 Mcfs. The u/s floor is at L 840 and crest is at EL 860. It will have 10 gates 50 ft. wide and 65 ft. high. The chute has a slope 1 on 4 and terminates in stilling basin at EL 635. The length of the stilling basin is 625 ft. The spillway alignment crosses an alluvial terrace. Sandstone No. s to 3 underlie the spillway. Two lines of vertical drainage wells shall be installed.

Orifice Spillway: The orifice spillway with its sill at EL 785 has a capacity of 1.0 M cfs at reservior level 930. By virtue of its low still it will also serve as mid level sluicing outlet. It would supplement d/s releases when the outlet capacity from Powerhouse and LLC falls short of irrigation demand. The spillway has 10 bays each 38 ft. wide with 33 ft. high radial gates. For energy dissipation a two stage stilling basin and a single basin alternative are being model tested for final decision. Flip bucket has not been considered because of weak rock in the plunge pool area. The spillway alignment crosses alluvial terraces and gravel filled Kharjwan nallah Sandstone beds 3 and 4 and associated claystone siltstone beds underlie the structure. The Kharjwan fault passes about 500 ft.away from the structure. A minimum factor of safety = 1 has been adopted for static stability of structure.

CONCLUSIONS

The selected site is comparatively less disturbed by seismicity. The rocks have gentle dips and at least 40 ft. thick sandstone is available under major structures. The site is well adopted to an earth and rock fill embankment. The structures can be laid out independently without any congestion. The excavation from different sections would be utilized in the body of the dam. Due to the river bend immediately d/s of centre line and the presence of Sanhi nallah there would be lesser length of diversion channel, and tail race channels. Because of less excavation for power house in the Sanhi nallah, there would be no problem of rebound. As the river remains in the gorge, there would be less problem of land submergence and population displacement. With the max 'conversation level at 925 minor protection works of Nowshera would be required. The project can be operated in conjunction with Tarbela and optimum utilization of water and power can be made. The project is nearer to load centre and well developed communication and transportation system exists.

BIBLIOGRAPHY

1. Feasibility Report (1975) Associated Consulting Engineers.

2. Project Planning Report Volume 1 to 13 (1983) Kalabagh Consultants.

3. Reports and Files Dams Review Cell, WAPDA.

4. Minutes of Meetings of Panel of Experts.

PROJECT DATA

Embankment dam:	
Crest elevation	945 ft. SPD
Freeboard above PMF level	8 ft.
Crest width	50 ft.
Upstream slope	1 on 2.5
Downstream slope	1 on 2
Maximum height above river bed	265 ft.
Total volume	36 million cu. yd.
Upstream Cofferdam:	
Crest elevation	785 ft. SPD
Length at crest level	1750 ft.
Underseepage control	Cement–bentonite slurry trench
Downstream Cofferdam:	
Crest elevation	765 ft. SPD
Length	1800 ft.
Diversion channel (concrete-lined):	
Invert elevation	682 ft. SPD
Bed width	400 ft.
Side slopes	1 on 2
Overall length	7000 ft.
Overflow spillway:	
Sill elevation	860 ft. SPD
Number and size of radial gates	10 N 50 ft. X. 60 ft.
Discharge capacity (RL-925)	0.92 M cfs.
PMF Discharge	1.1 M cfs.
Orifice spillway:	
Sill elevation	785 ft. SPD
Number and size of radial gates	10 N 38 ft. X 33 ft.
Discharge capacity (RL-925)	1.0 M cfs.
PMF Discharge	1.0 Mcfs
Power Station:	
Design head	187.5
Number of units	8
Installed capacity	2400 MW
Turbine type	Francis
Rated output at design net head	306 MW

Paper No 469

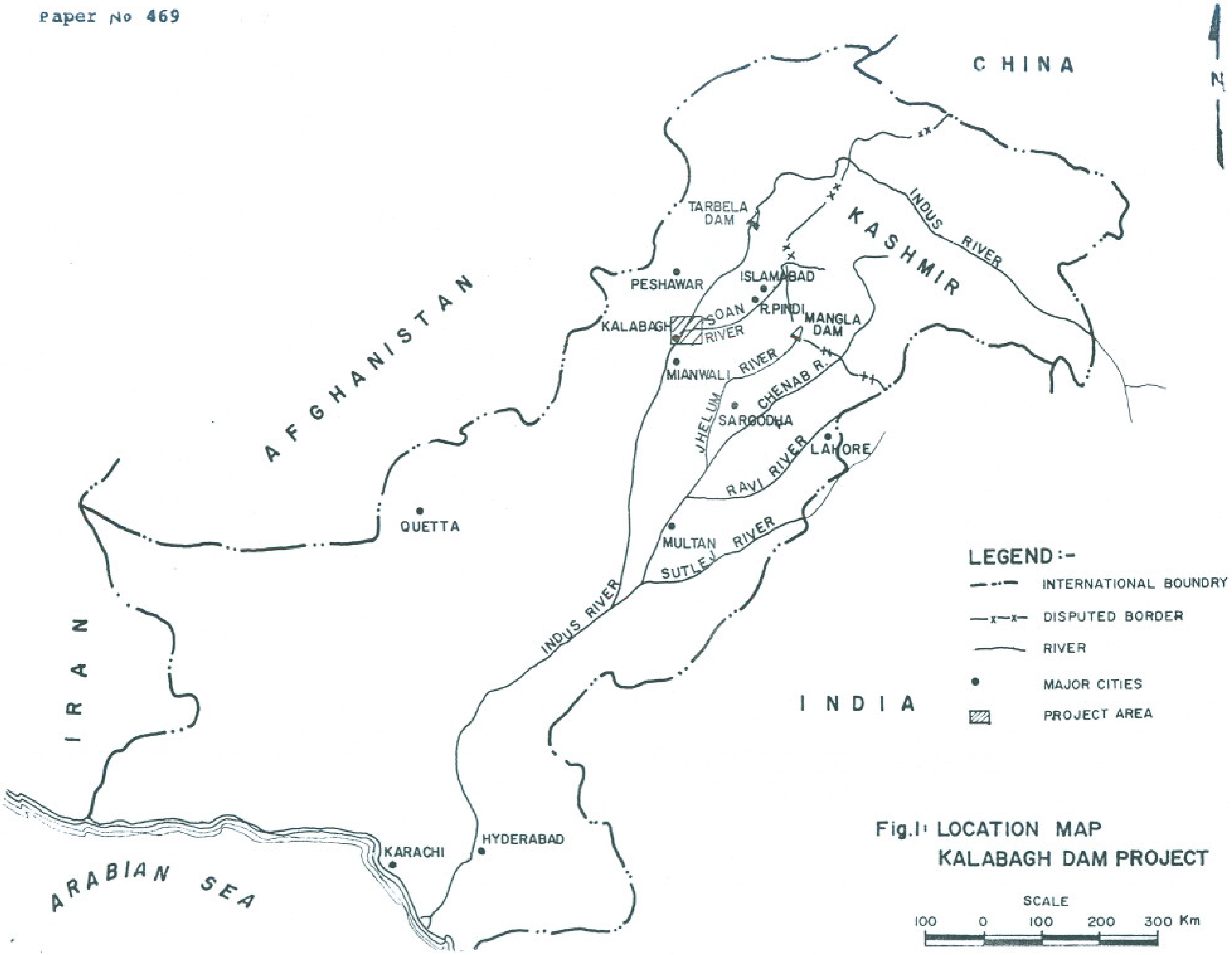


Fig.1: LOCATION MAP
KALABAGH DAM PROJECT

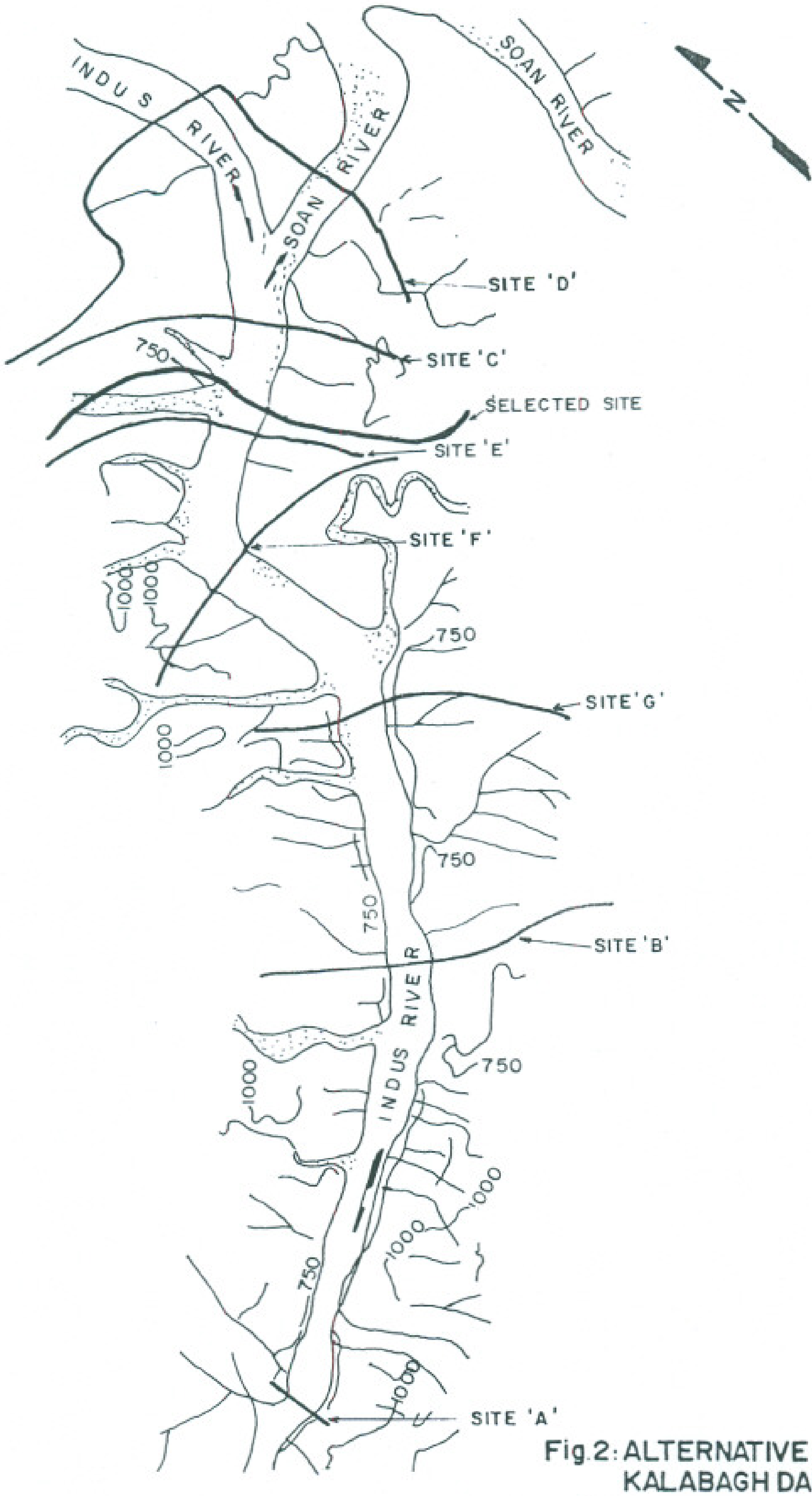


Fig.2: ALTERNATIVE DAM SITES
KALABAGH DAM PROJECT

SCALE
0.789 0 0.789 1.578 miles

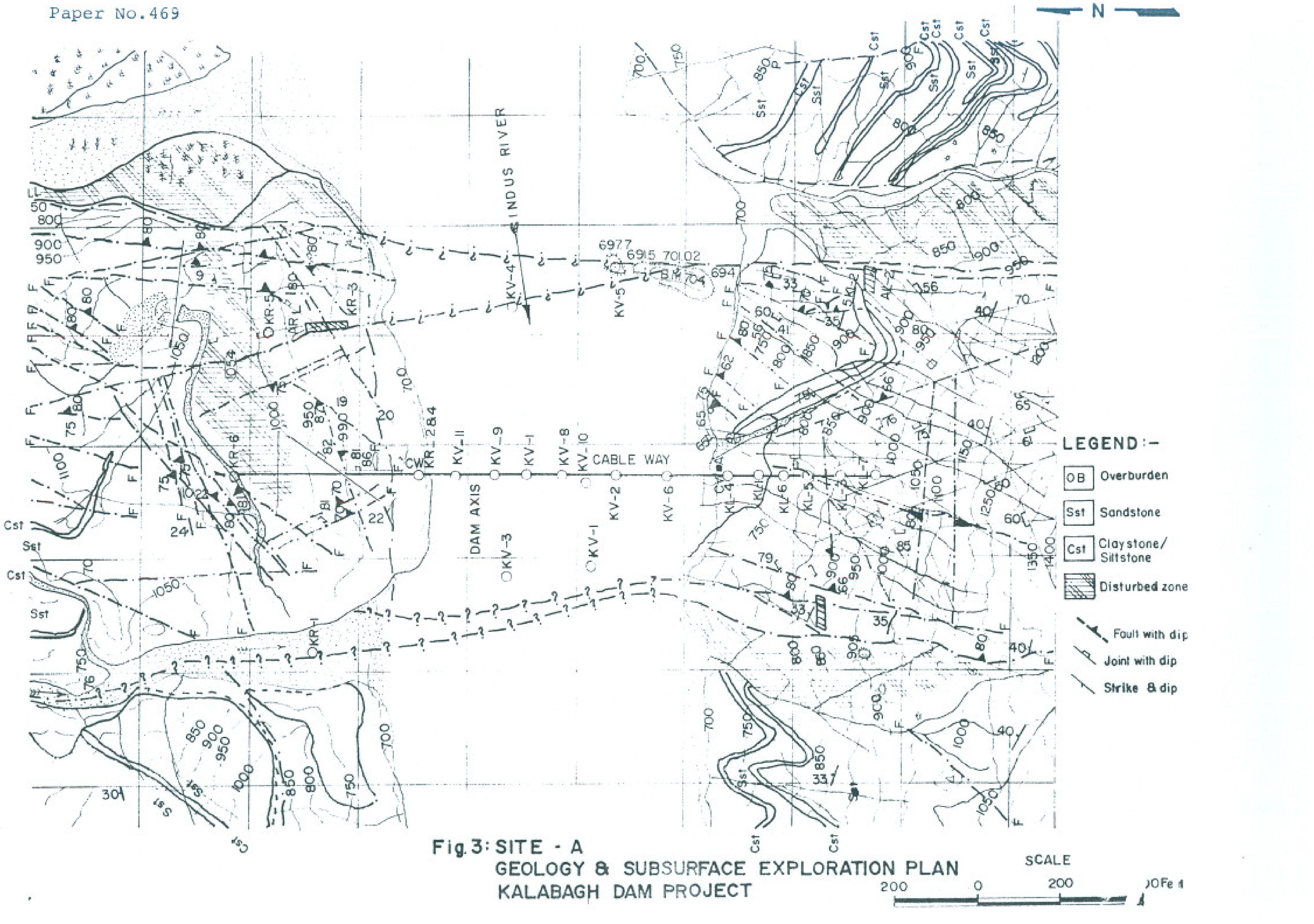


Fig.3: SITE - A
GEOLOGY & SUBSURFACE EXPLORATION PLAN
KALABAGH DAM PROJECT

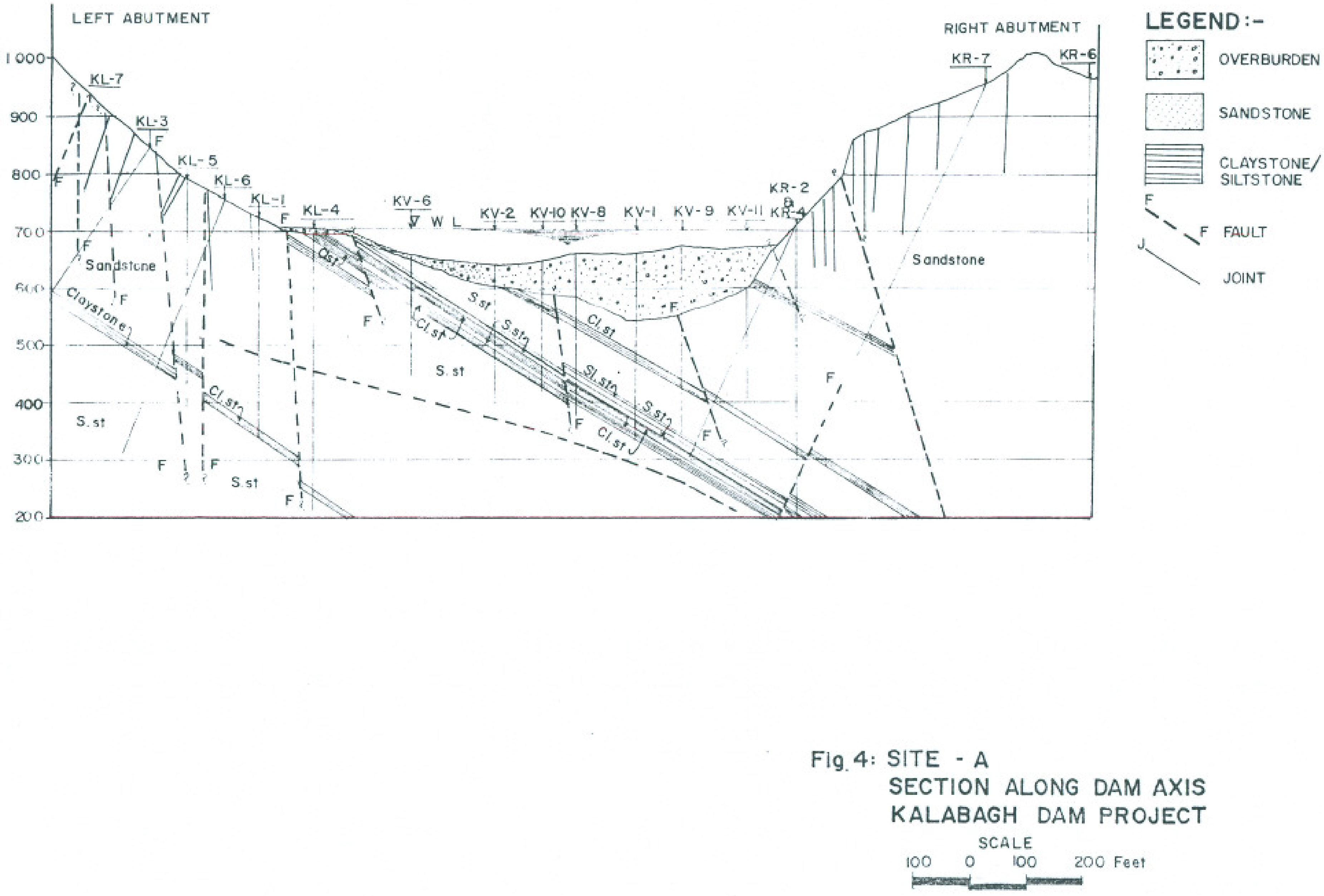


Fig. 4: SITE - A
SECTION ALONG DAM AXIS
KALABAGH DAM PROJECT

Paper No.469

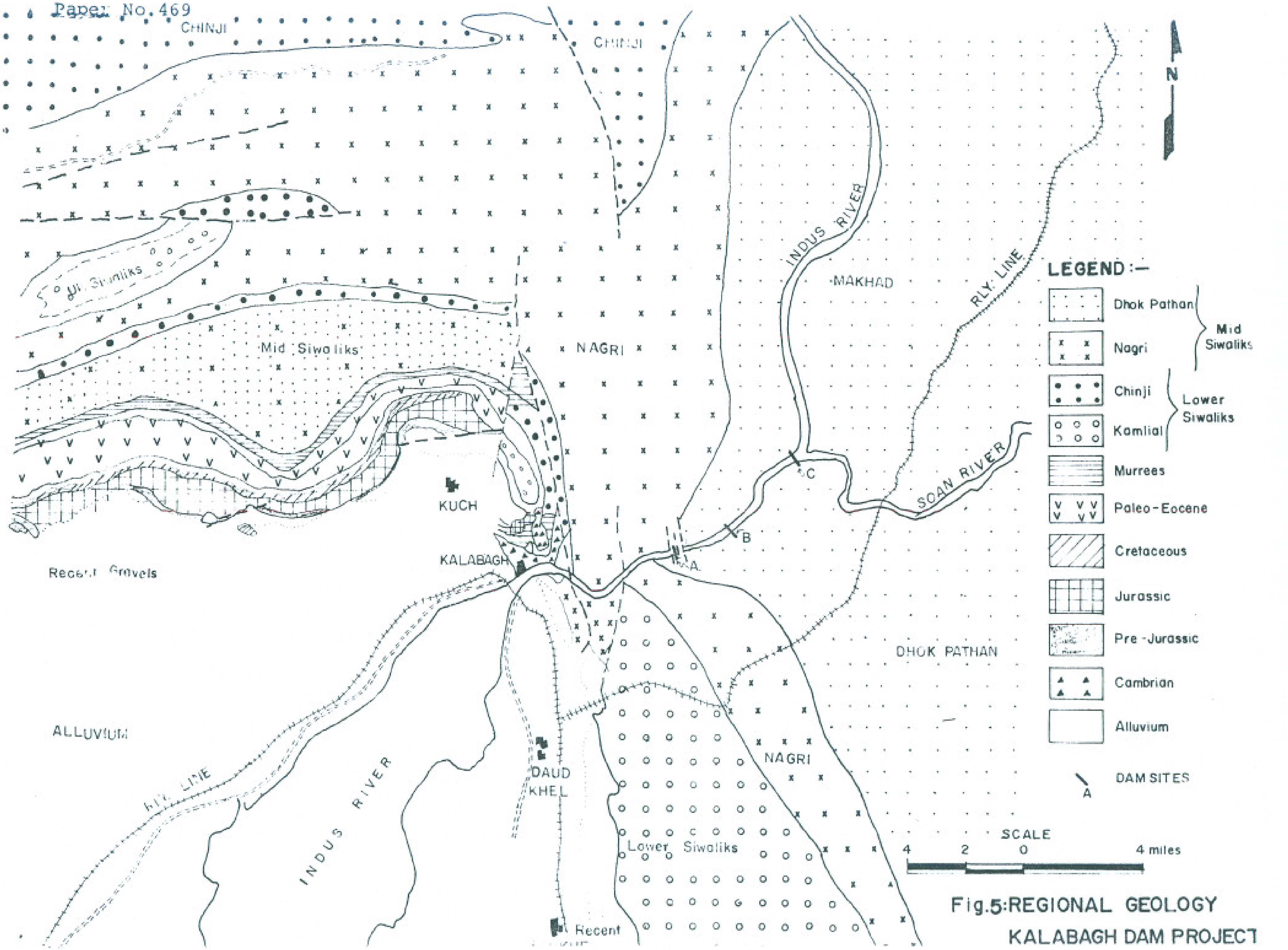
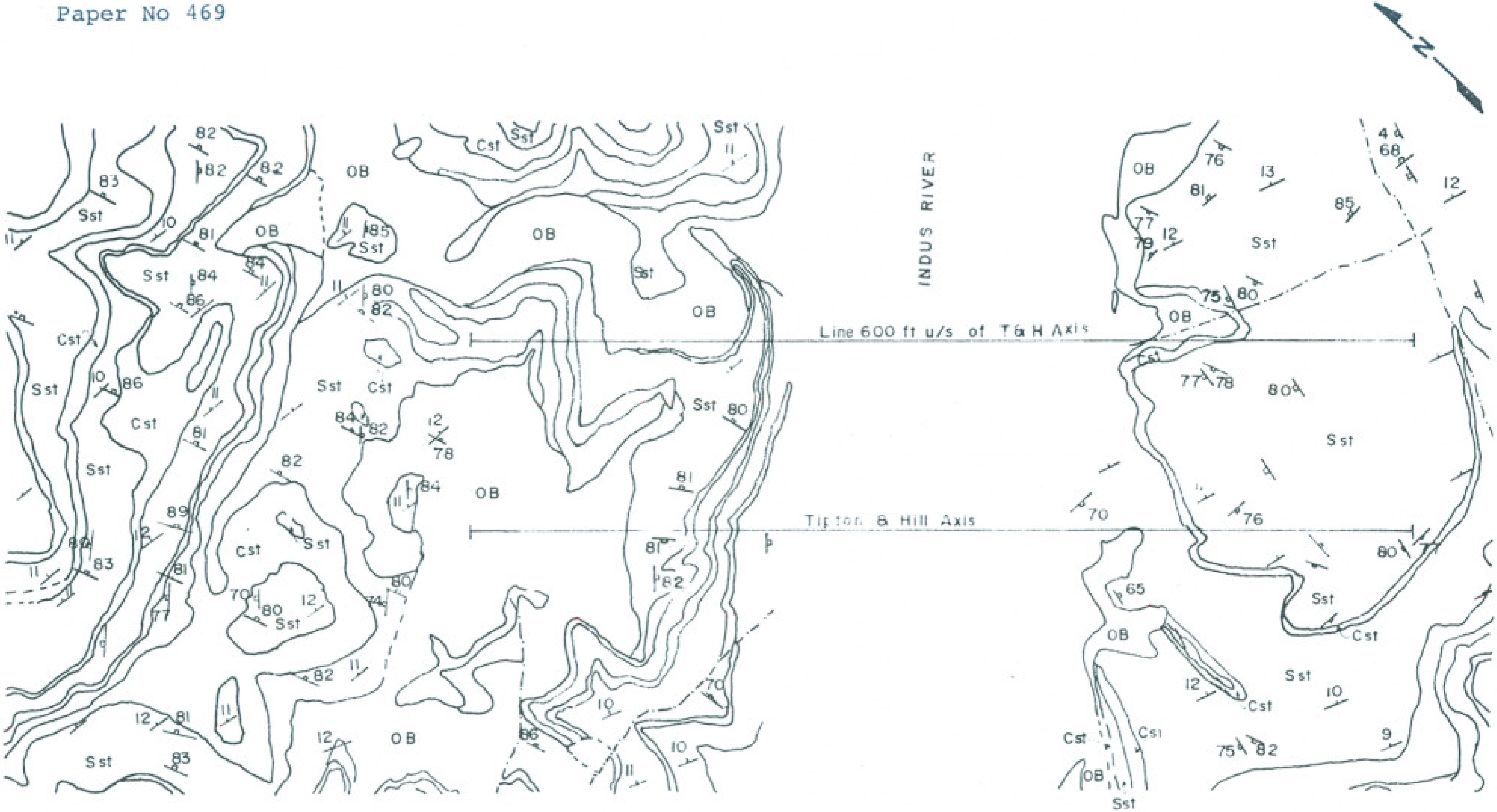


Fig.5:REGIONAL GEOLOGY
KALABAGH DAM PROJECT

Paper No 469



LEGEND :-

OB OVERBURDEN

Cst CLAYSTONE / SILTSTONE

Sst SANDSTONE

FAULT WITH DIP

JOINT WITH DIP

STRIKE & DIP

Fig.6: SITE - B
GEOLOGY PLAN
KALABAGH DAM PROJECT

SCALE
200 0 200 400 Feet

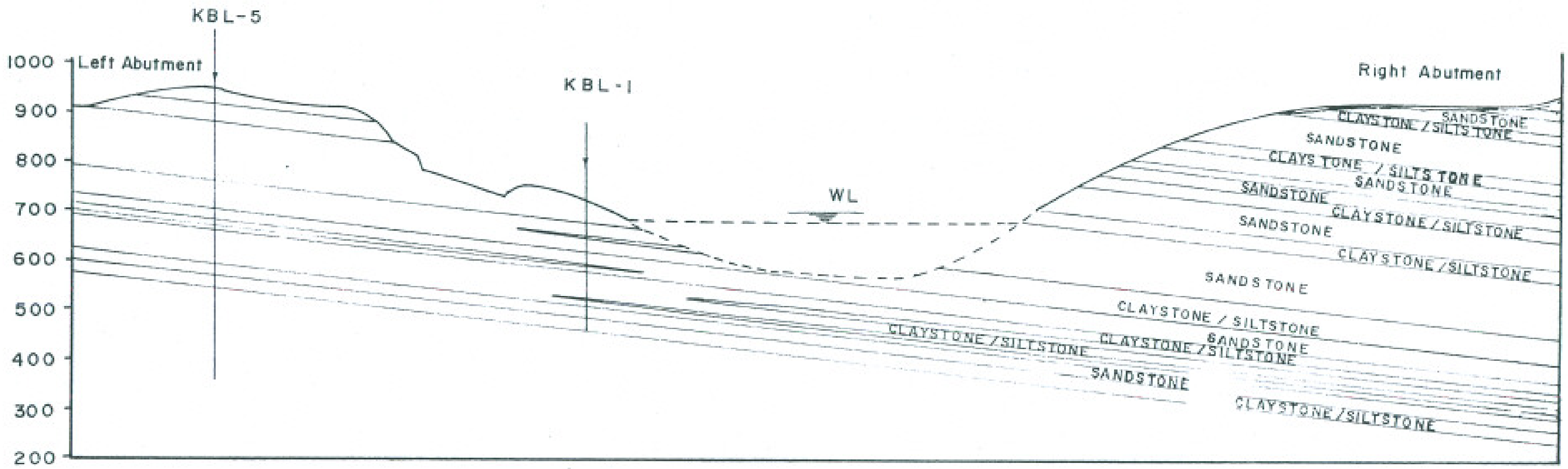


Fig. 7: SITE - B
GEOLOGY SECTION ALONG DAM AXIS
KALABAGH DAM PROJECT

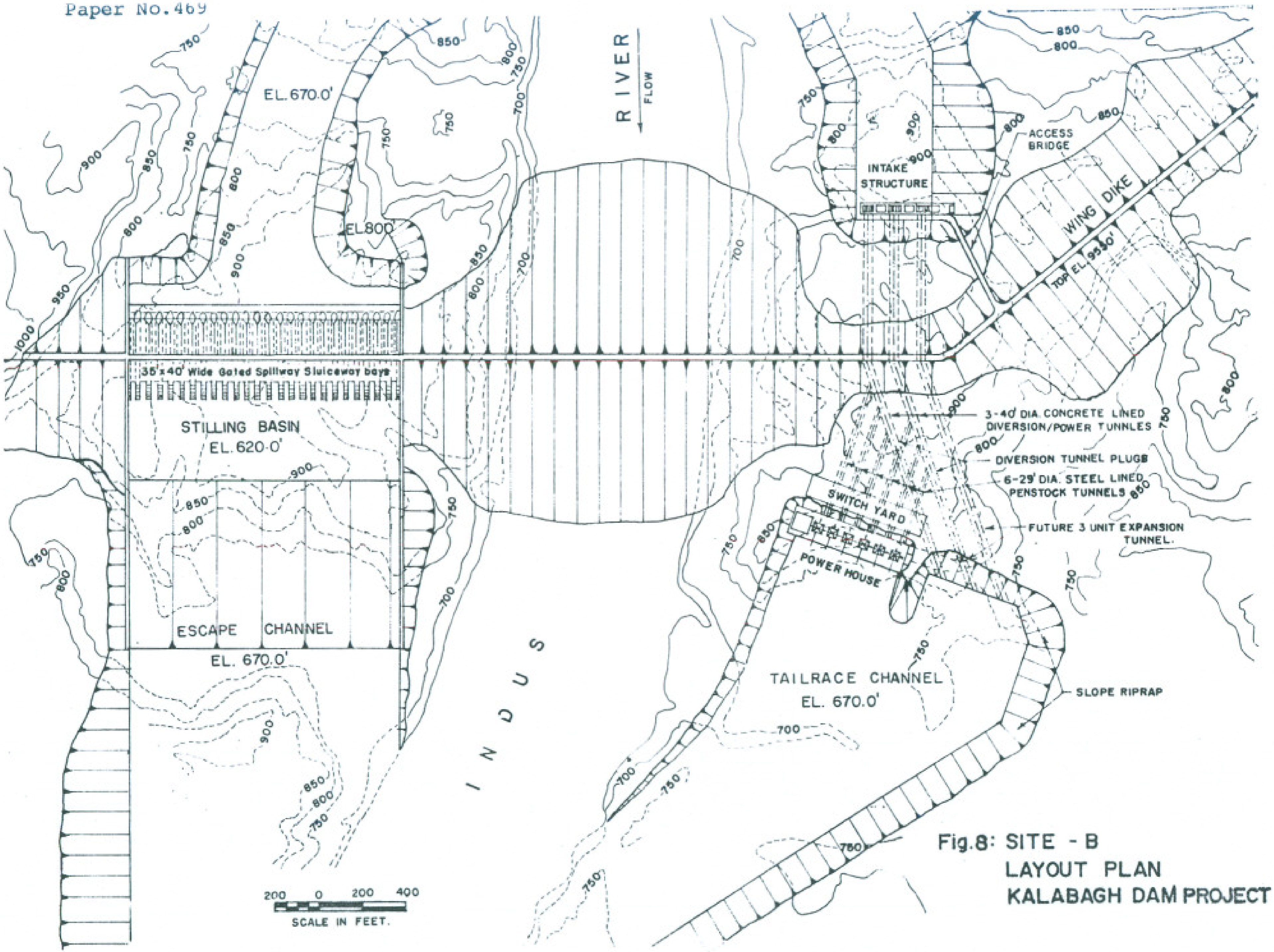


Fig.8: SITE - B
LAYOUT PLAN
KALABAGH DAM PROJECT

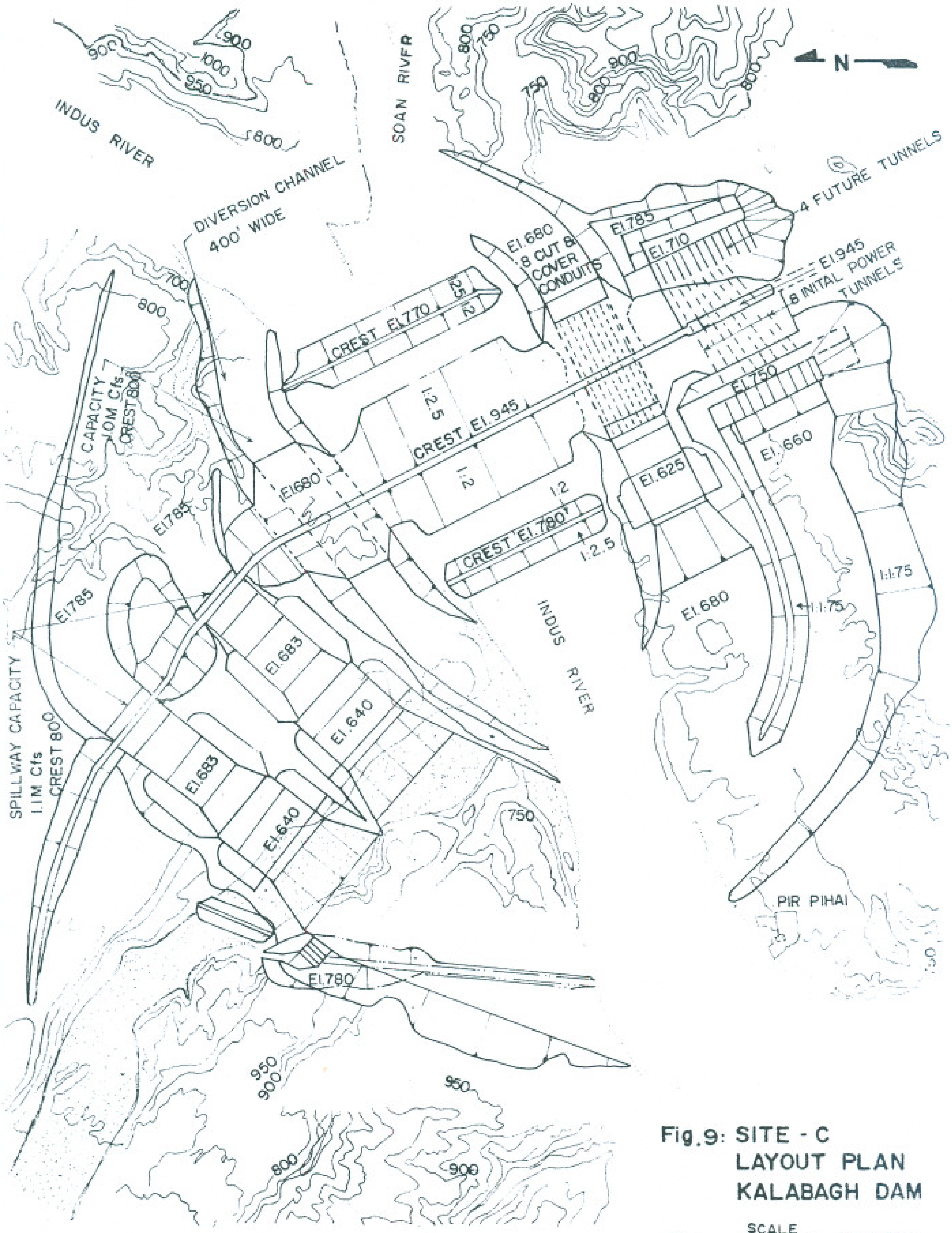


Fig.9: SITE - C
LAYOUT PLAN
KALABAGH DAM

SCALE
500 0 500 1000 Feet

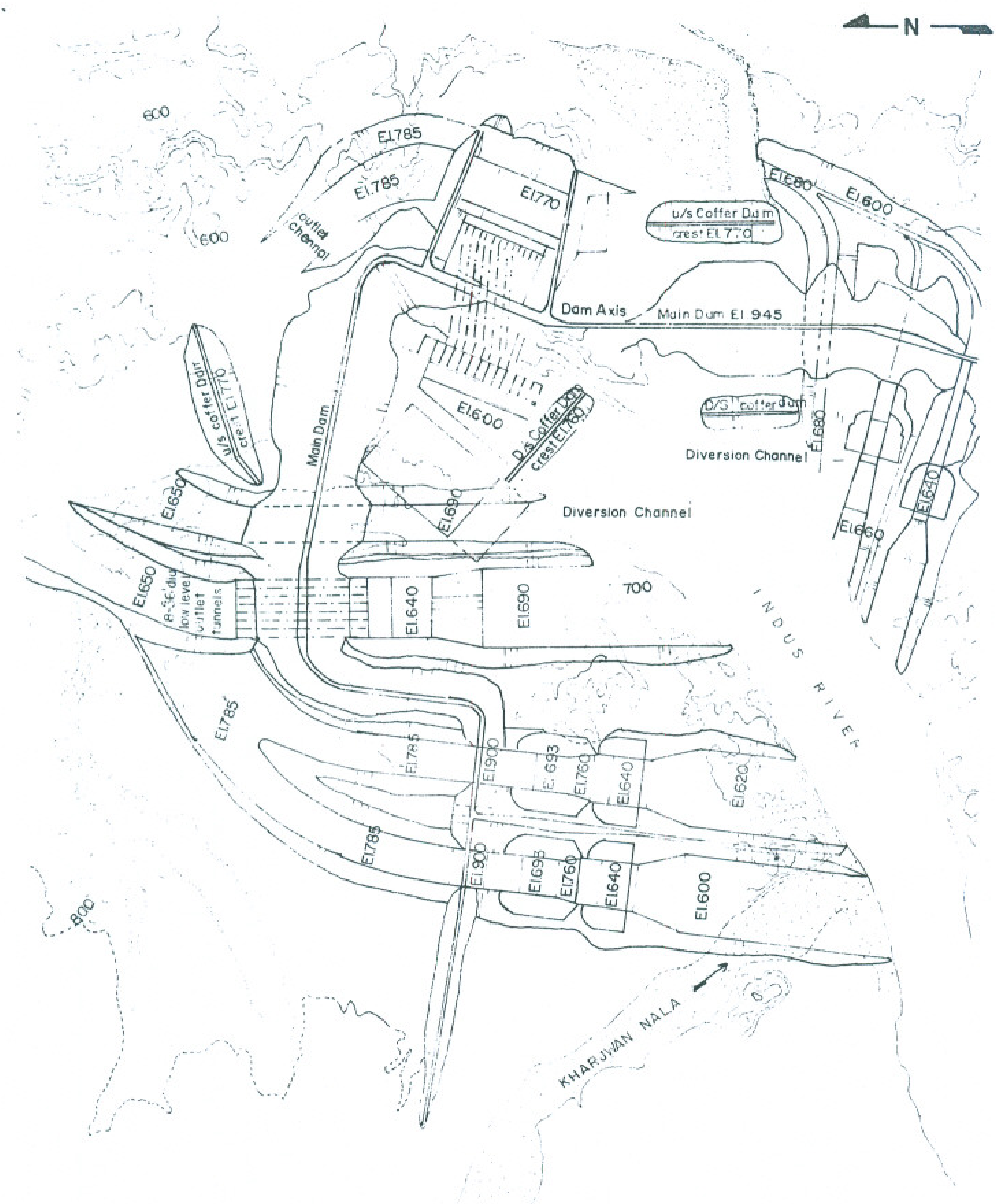


Fig.10: SITE - D
LAYOUT PLAN
KALABAGH DAM PROJECT

SCALE
500 0 500 1000 Feet

LEGEND :—

ITEMS	Completed	Nos & Footage	Planned
Bore/Drill holes before March 82	●	160 38,000'	
Bore/Drill holes from March 82 todate	⊙	192 31,000'	⊙
Test Pit	■	510 13000	
Deep Test Pit	◆		◇
Trench before March 82		50	
Adits before March 82		4 2300'	
Adits from March 82 todate			
Shaft			

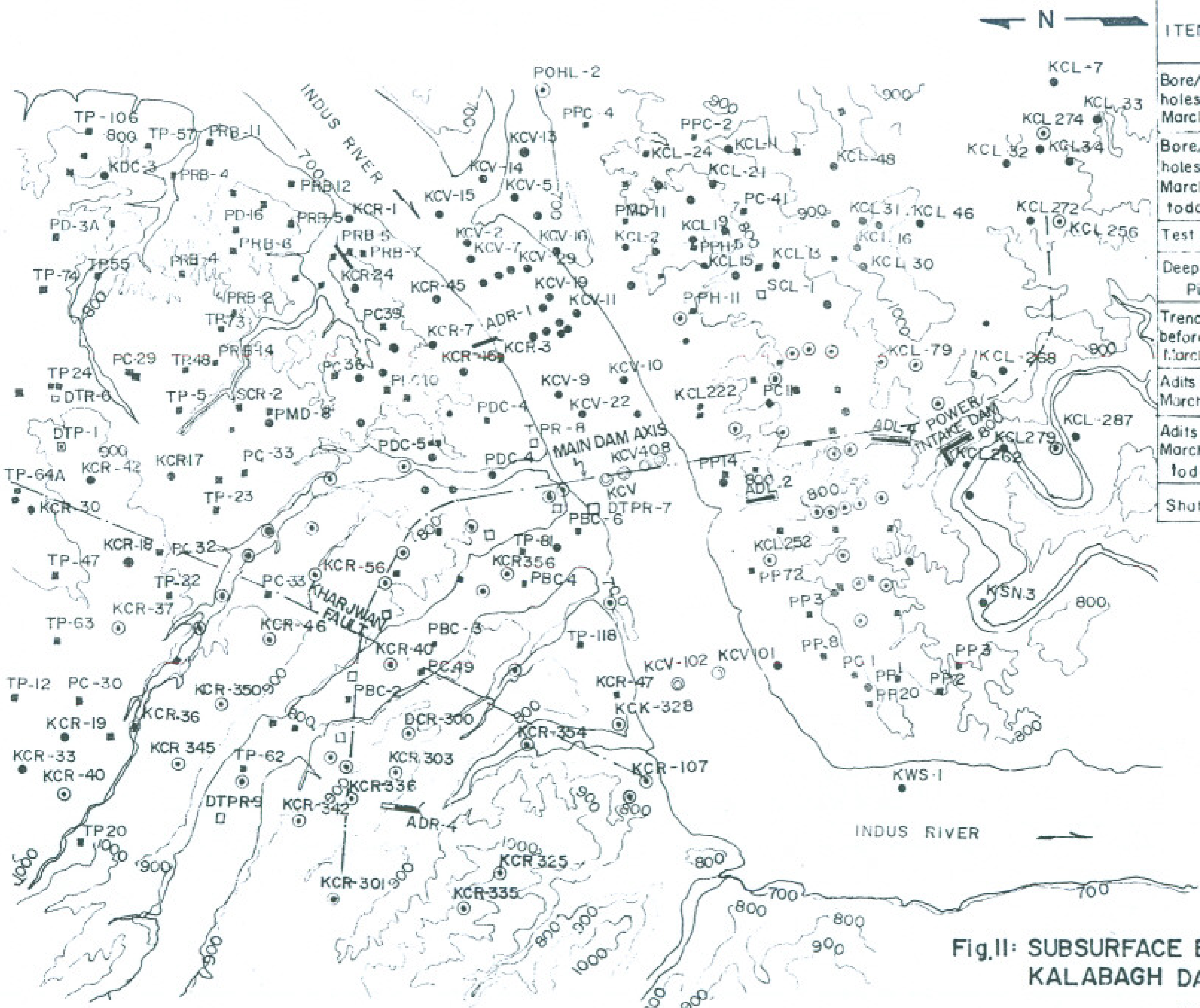


Fig.II: SUBSURFACE EXPLORATION PLAN KALABAGH DAM PROJECT

SCALE
500 0 500 1000 Feet

Paper No. 409

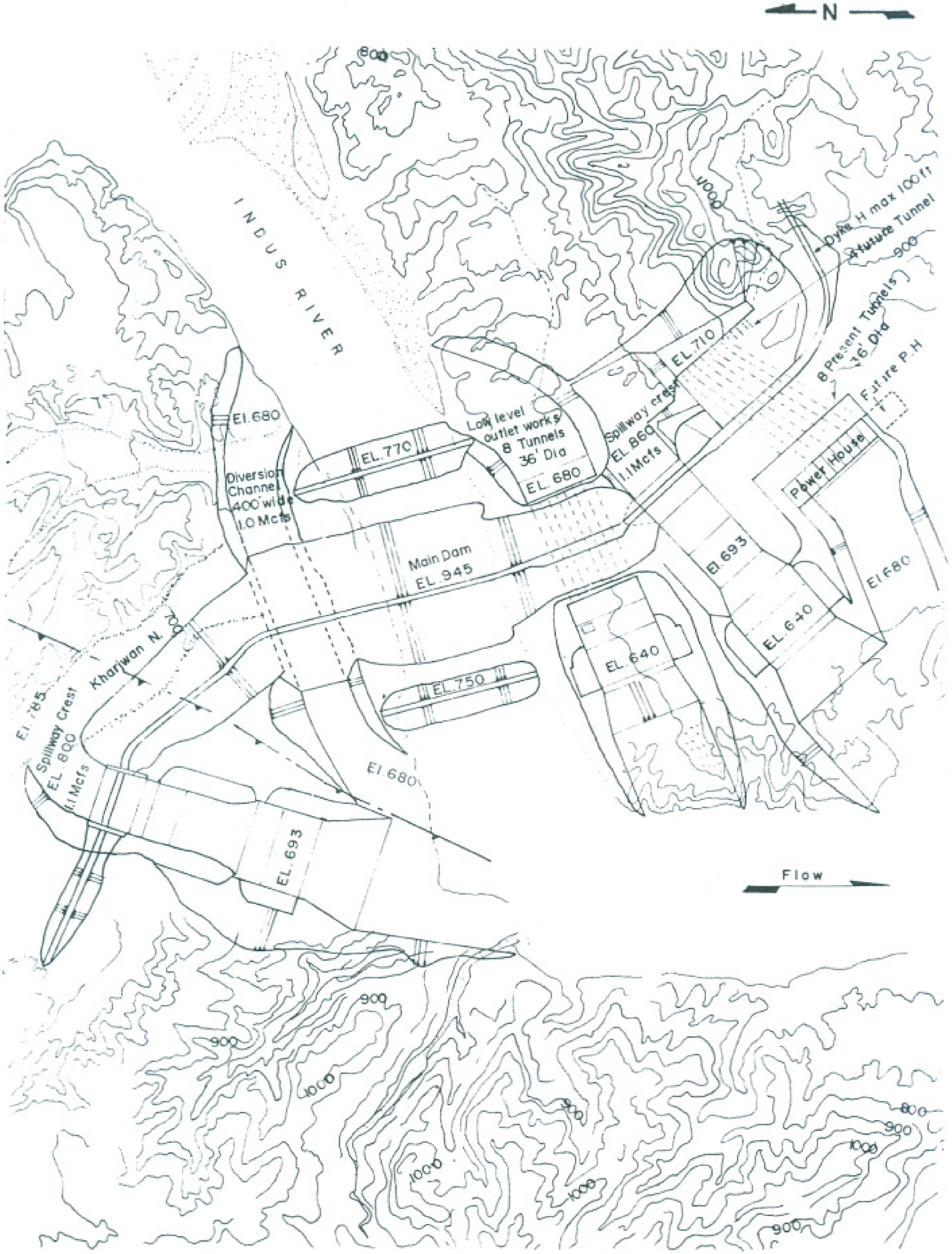


Fig. 12: SITE - E
LAYOUT PLAN
KALABAGH DAM PROJECT

SCALE
500 0 500 1000 Feet

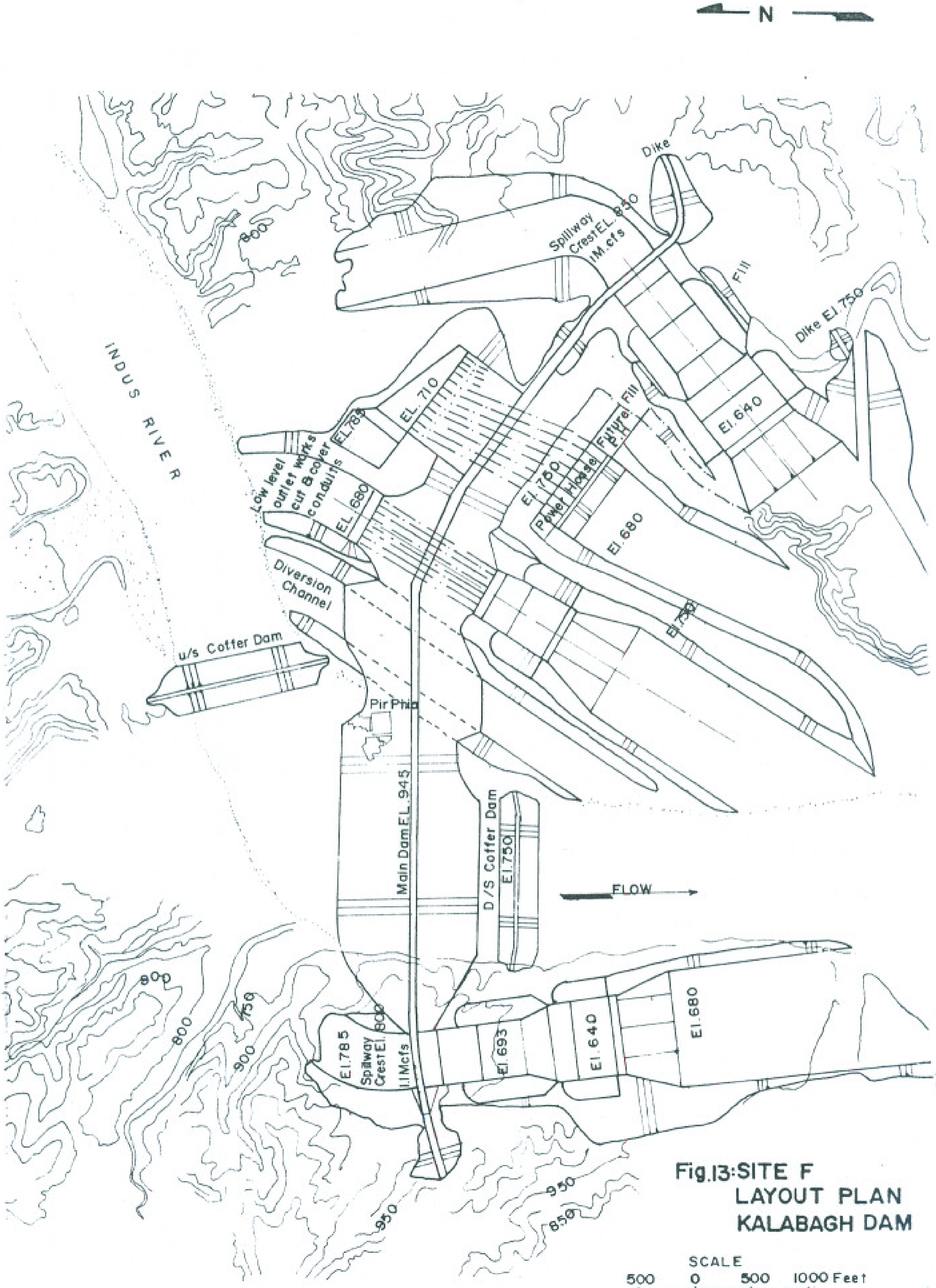


Fig.13: SITE F
LAYOUT PLAN
KALABAGH DAM

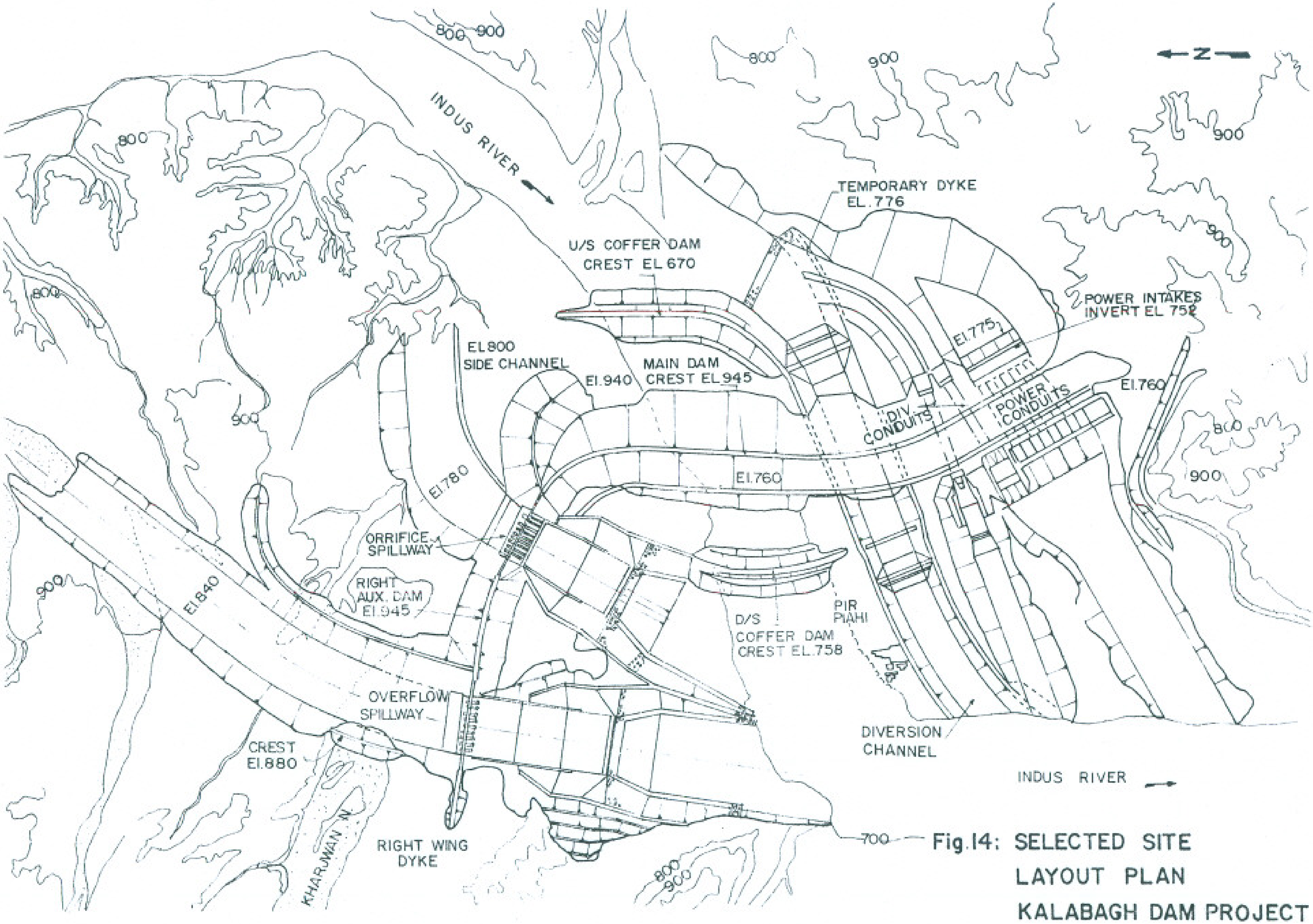


Fig.14: SELECTED SITE
LAYOUT PLAN
KALABAGH DAM PROJECT

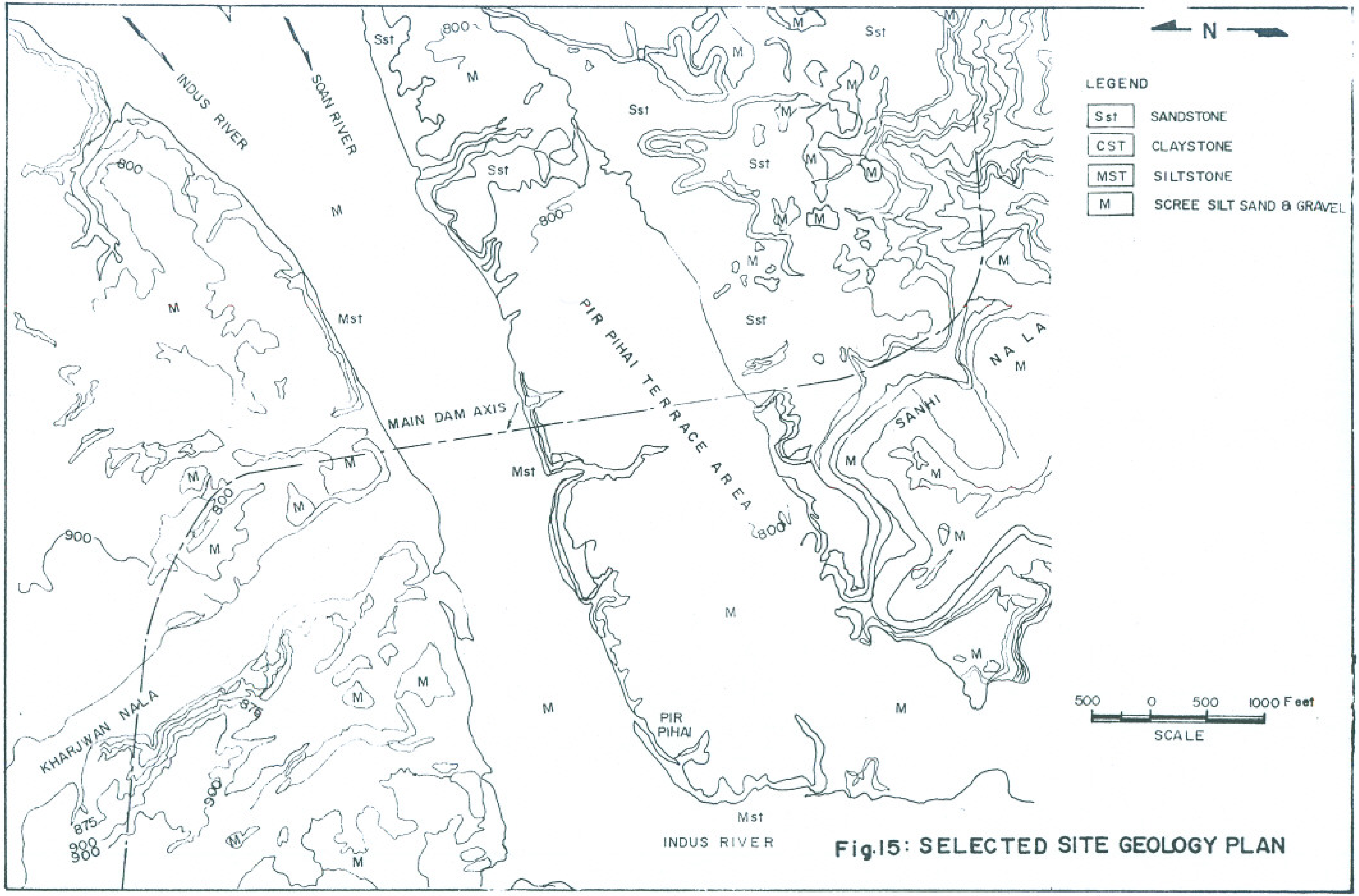


Fig.15: SELECTED SITE GEOLOGY PLAN

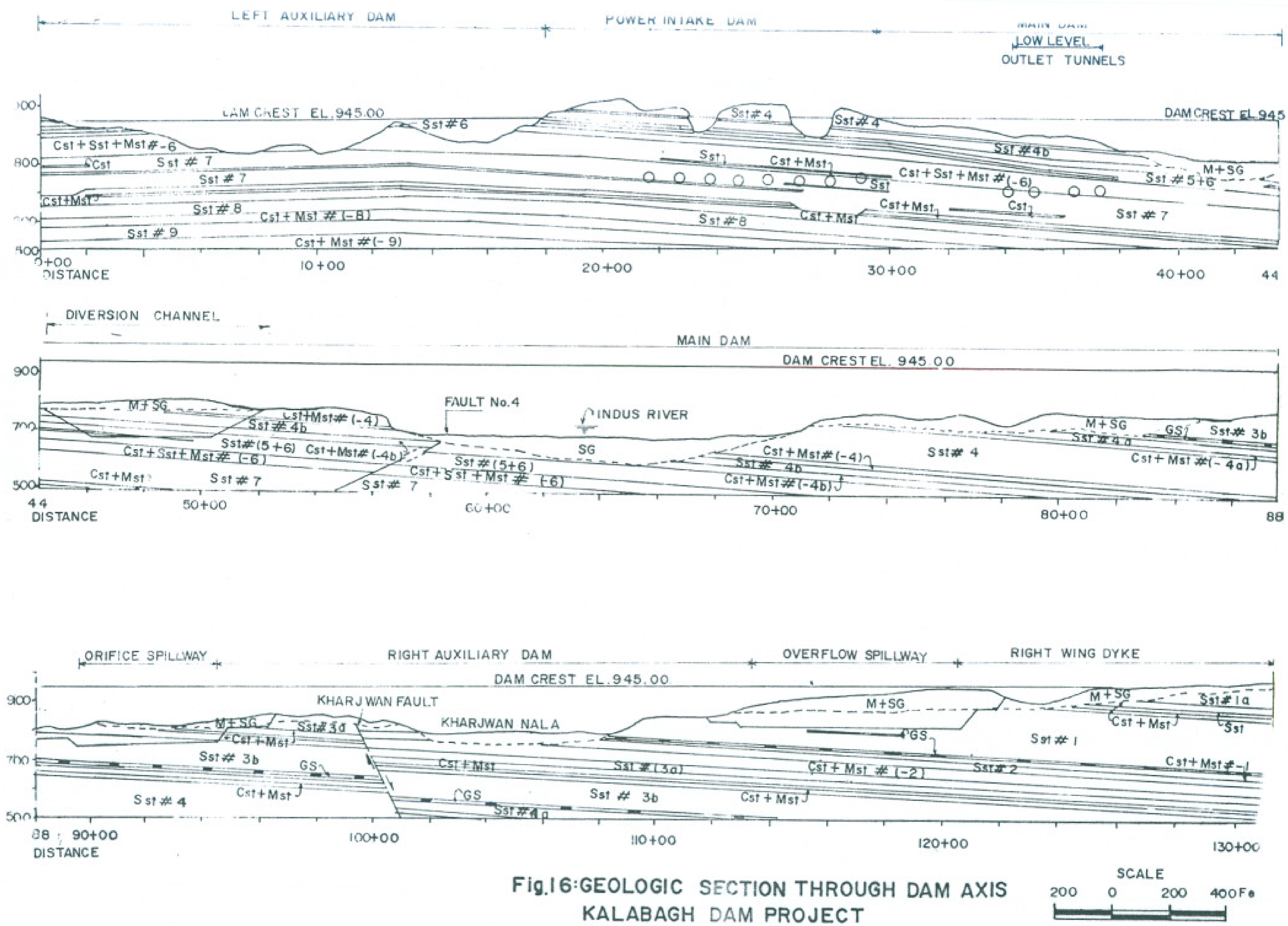


Fig.16: GEOLOGIC SECTION THROUGH DAM AXIS
KALABAGH DAM PROJECT

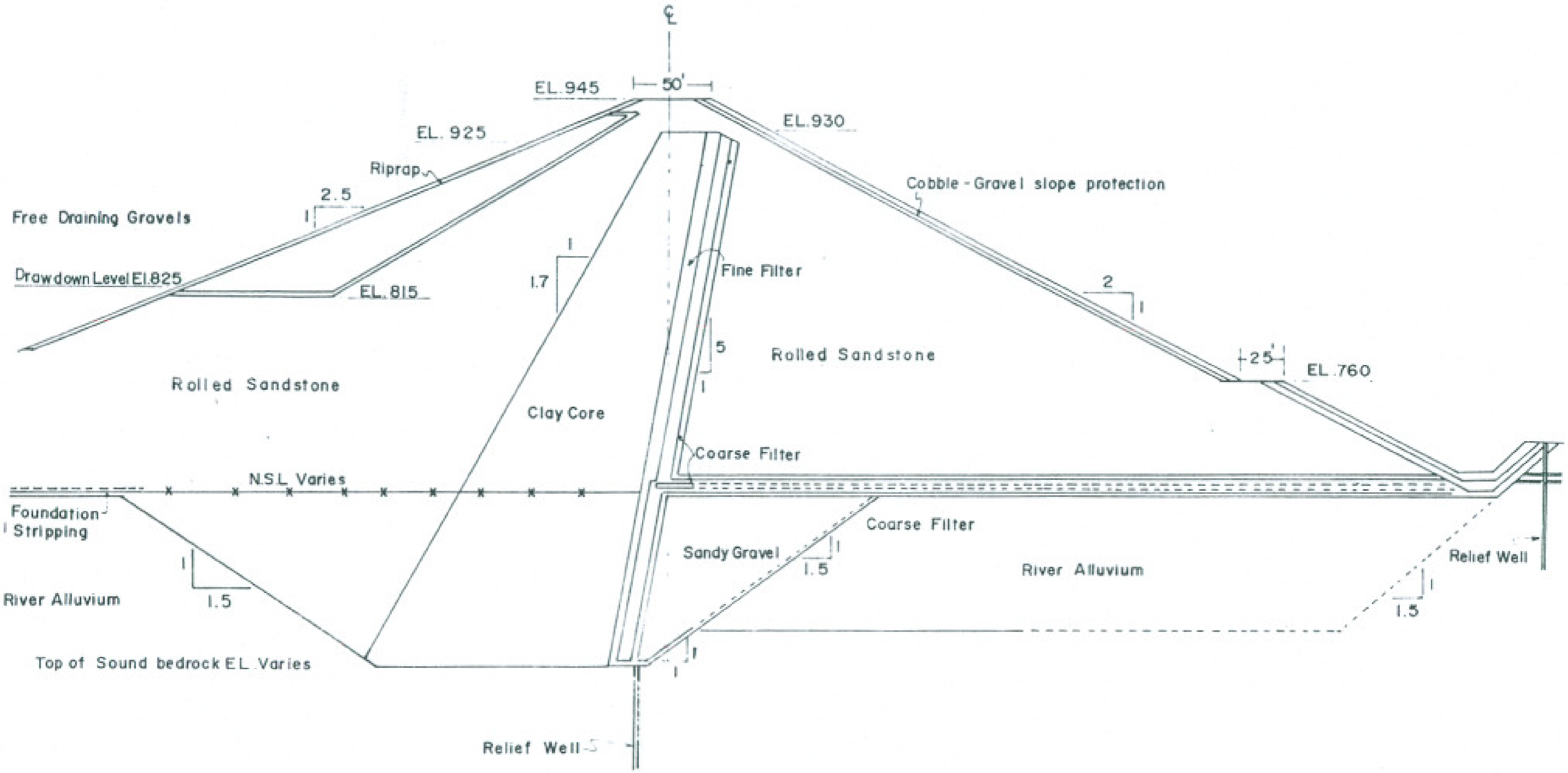


Fig.17: TYPICAL CROSS SECTION
MAIN DAM
KALABAGH DAM PROJECT

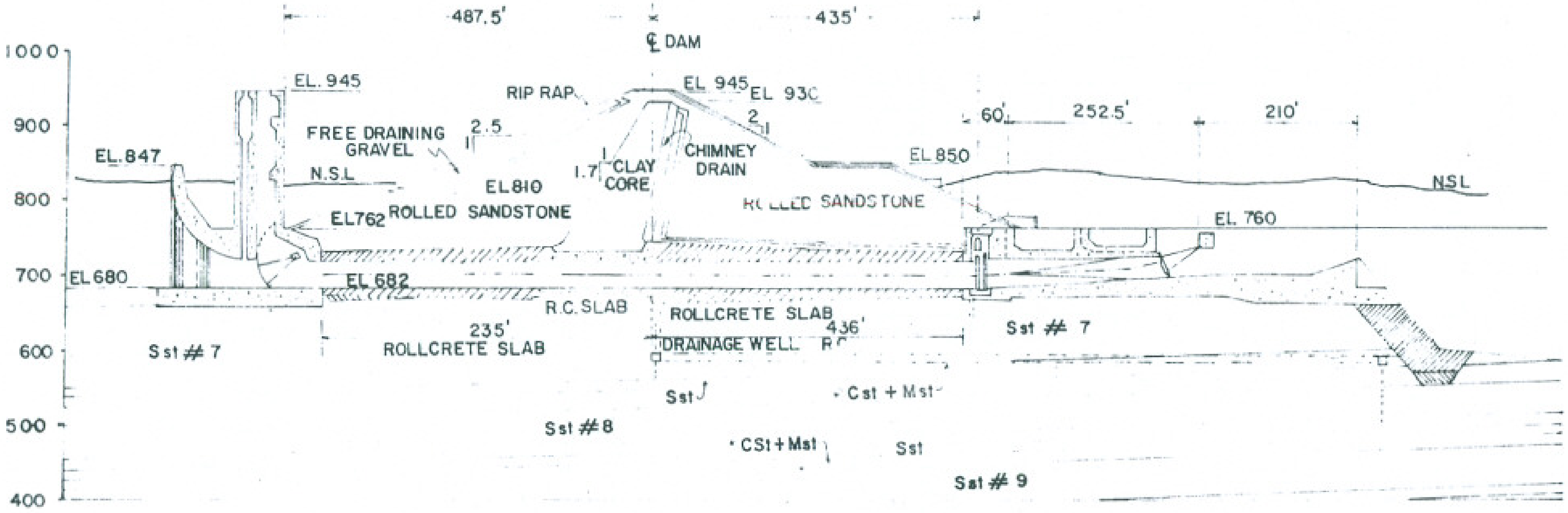


Fig.18: TYPICAL SECTION
L LOW DAM
KALABAGH DAM PROJECT

SCALE
100 0 100 200 Feet

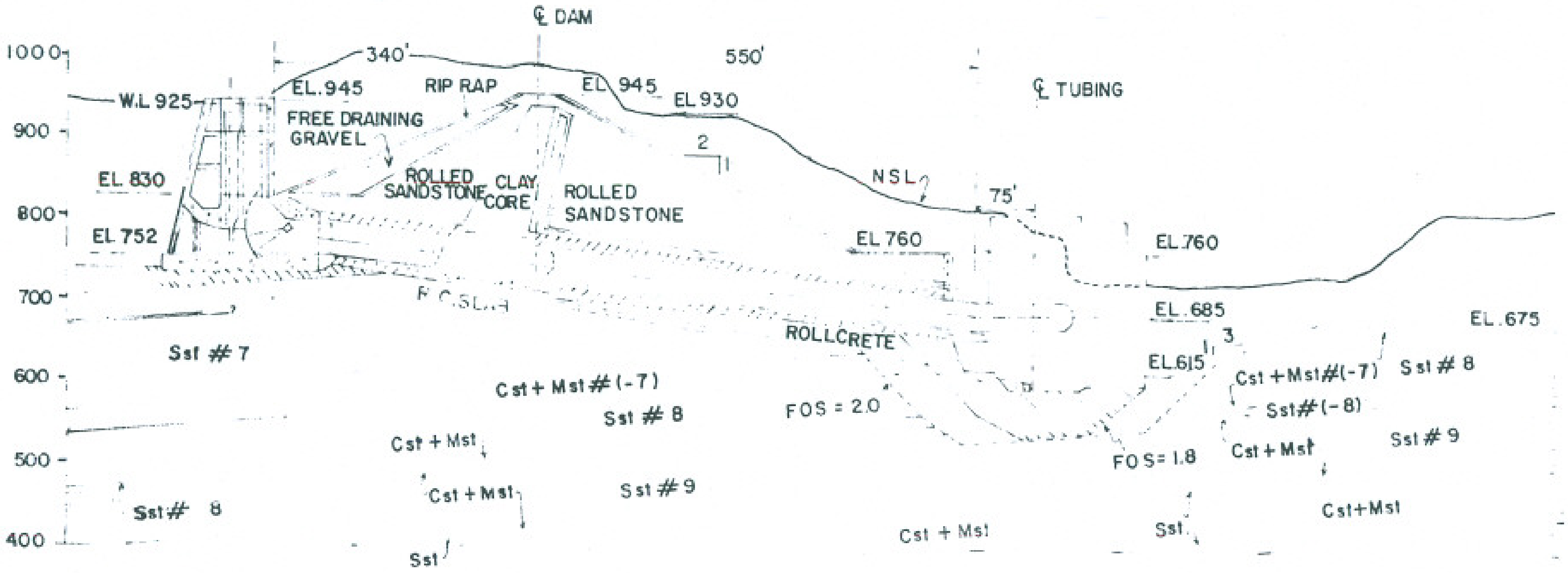
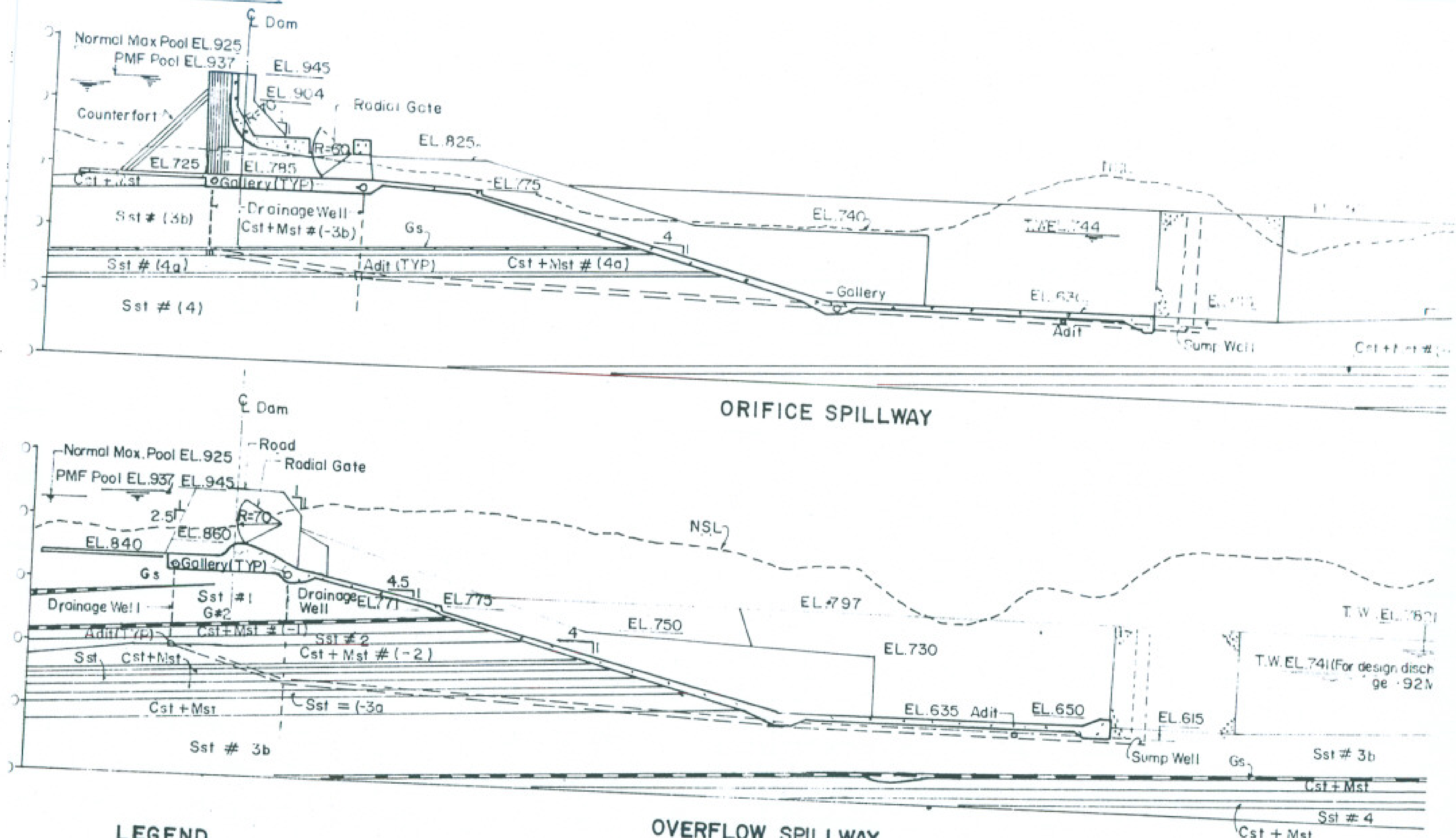


Fig.19: TYPICAL SECTION
POWER INTAKE DAM
KALABAGH DAM PROJECT



LEGEND

- #2 SANDSTONE (BED No. 2)
- #-1 CLAYSTONE + SILTSTONE (BED No. 1)
- GRAVEL BED (WITHIN Sst. bed rock)
- STONE PROTECTION

100 50 0 100 200
SCALE IN FEET

Fig. 20: SPILLWAYS LONGITUDINAL SECTIONS ALONG CENTRE LINES