

DEFORMATION MONITORING OF LARGE DAMS AND ASSOCIATED STRUCTURES THROUGH GEODETIC MEASUREMENTS

1. Introduction

Dams may be either man-made or exist because of natural phenomena, such as landslides or glacial deposition. The majority of dams are man-made structures mostly constructed of earth fill or concrete [1].

Large Dams, in general, are unique in their layout, and design. At the planing and design stage all the queries of the designers cannot be answered except through very detailed and expensive field investigations but there is limit to such investigations dictated by cost and time factors. Design therefore is based upon certain assumptions and calculated theoretical predictions regarding the behavior of the structure under different site conditions during the construction and later during the operation stage.

Structural and civil engineers traditionally incorporate instrumentation such as Strain gauges, inclinometers and extensometers into designs to measure ongoing structural movement. This type of instrumentation gives a good indication of significant relative movements within a structure but the measurements are usually too global in nature for detailed structural analysis. A second limitation of this instrumentation is that the measurements usually cannot yield enough precision to accurately model structural deformation [2].

Deformation monitoring is one of the requirements to keep track of the designers' assumptions and predictions in order to assess the behavior of the structures for safety reasons. The monitoring process can be carried out by different techniques using a variety of geodetic instruments available now.

2. Safety of Large Dams and Associated Structures

Public and property risks involved in case of a dam failure are very high because people have been allowed to settle below dams in potential inundation zones and further because new dams are being built in less than ideal sites.

The elements of risk include phenomena such as floods, earthquakes and landslides. These hazards threaten dam structures and their surroundings.

Recognition of the causes and possible impacts of dam failure points out the need for a program to enhance dam safety [3] and monitor its behaviour / performance. In the early days of the dam construction monitoring a dam's regimen under actual loading conditions was not given extensive thought, mainly because the need for instrumentation data was not recognized.

As more dams were constructed (especially embankment type) design specialists learned that much knowledge could be gained if the actual stress, strains and resultant deformations could be measured and the actual conditions could be compared with the assumed conditions. Further, there was growing awareness that any inordinate movement or knowledge of deterioration in condition of the dam would be of immense value in assessing the safety of the dam.

The World Bank requirements to help assure dam safety are;

1. Detailed review of the concept and design by an independent panel of experts, acceptable to the Bank during the early stage of design and during final construction.
2. Periodic inspection of the dam after construction by suitably qualified independent experts.

Review panel is required when the dam or embankment

- Exceeds 10 m in height above the streambed or creates a reservoir with gross storage volume of more than 2.5 million cubic meters.
- presents unusual design features and / or involves different geological conditions; or
- Is situated so as to be significantly destructive in the event of failure.

Adequacy of design includes appropriate instrumentation for monitoring the dam after construction.

Maintenance and inspection after construction includes periodic inspection program with adequate reporting and monitoring of result [4].

Deformation monitoring is therefore very closely linked to the safety of a dam and associated structures. The bursting of a large dam might cause enormous damages that could never be made up for. The authorities and the engineers have to take all precautions to prevent such a catastrophe. One such precaution is the regular and credible deformation monitoring of the structures to assess their performance and scientific evaluation / analysis of the results to drive rational conclusions. The conclusions, on the basis of which adequate and reliable remedial measures could be undertaken to avoid a mishap or disaster.

To this end for instance Swiss Government has laid down the obligations of the owners in a regulation on dams e.g. the determination of deformations of the dam and more important of the foundations and the abutments. The analysis of the dam is based on the design load on the dam. Thereby, the water load is precisely known, while the reaction of abutments and foundation can only be estimated according to geological tests. Further uncertain factors in the calculation are the elastic displacements of the abutments and foundation. The calculated stress-strain conditions therefore have to be checked by measurements. If differences occur between calculated and actual behaviour, investigations have to prove the safety of the dam. Otherwise costly remedial measures have to be taken to ensure that nothing untowards happen. Thus precision and accuracy / credibility of the deformation measurements are of major importance [5].

3. Movements

Movements occur in every dam. They are caused by stress induced by reservoir water pressure, unstable slopes, low foundation shearing strength, settlement (compressibility of foundation and dam materials), thrust due to arching action, expansion resulting from temperature change, and heave resulting from hydrostatic uplift pressures[1]. They can be categorized by direction:

Horizontal Movement – Horizontal or translational movement commonly happens in an upstream – downstream direction in both embankment and concrete dams. It involves, the movement of an entire dam mass relative to its abutments or foundation.

Vertical Movement – Vertical movement is commonly a result of consolidation of embankment or foundation materials resulting in settlement of the dam. Another cause is heave (particularly at the toe of a dam) caused by hydrostatic uplift pressures.

Both these movements can be effectively and accurately measured through geodetic measurements.

4. Geodetic Measurements

These measurements provide the information on absolute movements relative to some fixed datum considered stable and least susceptible to suffer movement due to loading and unloading of Reservoir. Monitoring of the reference datum extend over a long period of time scale starting from initial fixation at the pre-construction stage and through construction phase and continued into the post construction period of the project. Complete history of the reference datum is as important as that of the points under observation which are located on the structures.

These measurements provide information on the behavior of the structure under study. The accuracy of the geodetic surveys may be inadequate and uneconomical in some cases, when a high frequency of repeated observations is needed. In addition, terrestrial geodetic surveys require intervisibilities between survey points, which limits their application. Geotechnical instruments may easily be adapted for continuous monitoring and if properly calibrated and installed, can provide high accuracy results. These instruments, however, supply only very localized information on a selected component of the deformation (e.g. only local tilt or local extension in one direction when using a tiltmeter or an extensometer, respectively) [5].

Massive excavation may involve removal of large rock or overburden and may result the foundation floor to rebound in certain geological formations. This situation requires monitoring through geodetic levelling. In another situation placement of huge quantities of materials e.g. concrete, or rock and earth fills, may cause settlement that must be monitored.

We therefore need properly located and constructed network of accurately measured control points in the project area before the commencement of construction

activity. The deformation measurement programme has to guarantee the continuity of the reliable measurements over a long period of time. The network of points layout and selection of their location to satisfy the continuity condition is thus important.

4.1 Survey Monuments

Survey Station used as a reference point must be physically well built and defined by a permanent and adequately sited on sound and stable ground. Ideally the survey station and the target station should be such that setting up error is zero or as close to zero as possible further as far as possible it must be free from external natural and man made influences. Tests have found [6] that concrete survey pillar can change position by more than 1mm (1/25inch) during a two hour period apparently because of unequal heating and cooling.

Concrete Pillar as shown on Plate No.1 is the most popular design used in Pakistan and else where in the world. Its foundation design and anchors in the rock or ground are modified as per the site conditions. The instrument plate at the top of the pillar is of two types i.e. screw on type or 120 degrees groove type reference Plate No.2. The selection of one or the other is dependent upon the elements of vandalism in the area. The screw on type is susceptible to damage whereas the groove type is safer.

For target the most common type of marker is pipe or brass stud with screw on arrangement refer Plate No. 3.

4.2 Positioning and Monitoring Surveys

Fundamentally there is little difference in the surveying techniques used in both positioning and deformation monitoring measurements. The difference lies in the application and approach to optimization of the methodology.

In deformation surveys one is not interested in the absolute values of the observables with reference to the national geodetic system but in changes in observations and displacements of points derived from them. Therefore, in deformation surveys the influence of systematic error is not harmful as long as the errors are the same in all the repeated surveys. For example the effects of refraction, scale error or similar errors in electronic distance measuring (EDM) devices, have no significant influence on the accuracy of the calculate displacements if these elements mentioned above remain unchanged in all subsequent surveys. It is for this very reason that it is recommended that the same instruments at the observing stations and the same surveyor carry out the measurements in preferably similar environmental conditions.

4.3 Geodetic Instruments

There is a whole array of instruments available for monitoring deformation the three basic are;

-vertical measurement,

leveling instrument (conventional and electronic)

Leica N-3 Precision Level fitted with parallel plate micrometer and using Invar staff.

Standard Deviation for 1 km double run levelling = +-0.2mm

Leica Digital Electronic Level NA3003 with Invar staff

Standard Deviation for 1km double run levelling = +-0.4mm

-horizontal measurement

Distance measurement using electronic distance measuring (EDM) devices

Leica EDM – DI2002

Standard Deviation = 1mm + 1 ppm

-Angle measurement

Leica T1800

Angle measurement accuracy (Hz & V) = 1 sec of arc

-Electronic Total Station

Leica TC1800/L

Distance Measurement accuracy = 1mm + 2 ppm

Angle Measurement Accuracy (Hz & V)= 1 sec of arc

5. Warsak Dam

Case Study of Deformation Monitoring

The first inspection of Warsak Dam was undertaken by Dam Monitoring Organization (DMO) jointly in collaboration with the Survey Residency of Tarbela Dam Project sometime in 1983.

This project did not inherit survey control network from the construction period and a network of BMs and horizontal control was established a consequence of the first inspection.

The Figure No. 1 is the schematic diagram of the vertical control network used at Warsak . It was reconfirmed during the second periodic inspection (Dec.86/Jan.87) by visiting and relevelling the BMs. It was found in good state except that some BMs were found damaged.

The horizontal network given on Figure No.2 was a disappointment because it was incomplete and a very poor attempt to provide a triangulation scheme. It negates the basic principle that to avoid disappointment and to increase the reliability of the monitoring surveys, a properly designed monitoring scheme should have a sufficient redundancy of measurements using different measuring techniques and such geometry of the scheme that self-checking, through geometrical closures of loops of measurements [7]. It appears that no one made an attempt to verify whether the stations were inter visible before fixing them on the ground, for example the first quadrilateral WA1-WA2-WA3-WA4 is good the next one WA4-SB2-SB3-WA3 has one leg (SB3-WA3) missing, these stations are not inter visible. Thus there is a break in the network and this makes it useless.

The station WB1 is fixed from two stations WA3 & WA4, it is a narrow triangle, it is a very poor fix. The station WB1 is the main station from which all the fixations and monitoring of points located on the Powerhouse is carried out. The quality of monitoring is dependent upon the quality of the reference station plus the quality of measuring instruments and procedure.

These deficiencies were noted during the second periodic inspection and re-establishment of a credible horizontal control network was recommended Figure No.3. This is a very well balanced triangulation scheme but unfortunately it has not been implemented.

Warsak Dam deformation monitoring program is a classical case of mismanagement of a vital component of Dam Operation and Maintenance (O & M) activity. One should keep in mind, however, that establishing a poorly designed and unreliable monitoring scheme is a waste of time and money, and it may lead to harmful misinterpretation of the deformation. [7].

6. MANGLA DAM Case Study of Deformation Monitoring

This project came on line when there was more awareness among the dam engineers about the need and importance of deformation monitoring of structures through geodetic measurements. Further for the good luck of the project the survey group of Mangla Dam consultants was headed by a very experienced Chartered Land Surveyor who established a credible triangulation and BM control network throughout the project site for use during the construction and post construction period for deformation monitoring.

At Mangla Dam deformation monitoring of various structures was commenced during the construction stage and continued in the O & M stage. The project layout is given in Figure No.4, the Primary & Secondary Control Network is given on Figure No.5 which covers the major critical components of the project and Figure No.6 carries the Primary Control Network of Jari Dam component.

There are dozens upon dozens of deformation monitoring points located on all the structures of the Project. It is a fact that this is one of the very well monitored projects in the world. The survey manpower was well trained during the construction

stage in the geodetic measurement and computation procedures including the presentation of the results. All aspects were well documented and formed part of the O & M Manual, Figure No. 7 through to 14 are samples of the same.

7. TARBELA DAM Case Study of Deformation Monitoring

This project inherited all the good lessons learnt at Mangla Dam and the core of the Survey and Measurement Section of Tarbela was made up of the professionals and para professionals trained at Mangla.

For deformation monitoring aspect Tarbela is stated to be highly instrumented project. Here also movement monitoring commenced during the construction stage and continued into the post construction period as part of the O& M. Survey manpower has been well trained in the procedures of geodetic measurements and computations including the presentation of the results.

During the periodic inspections it was found that Survey Group at the project were doing a credible job. At the time of 2nd Periodic Inspection the existing major network was verified through re-measurements and found in excellent state, the horizontal distance computed from coordinates is compared with the measured value Figure No.15, the agreement varies from 1:35,000 to 1: 4,900,000, the average is well above 1st order work.

The site BMs were verified by connecting them to the off site permanent BMs and the results were well within the 1st order accuracy.

8. TESTING, ADJUSTMENT AND CALIBRATION OF GEODETIC INSTRUMENTS

Measuring equipment (rotation, vertical or horizontal distance), where used for collection of data require testing, adjustment and calibration at the start of the job and subsequently at regular interval to ensure accuracy and consistency during use. Tolerances of various instruments are known before their use and the accuracy of measurement to be achieved is also known, this information will facilitate the testing procedures.

The problem of instrument calibration is very often underestimated in practice, not only by the users but also by the manufacturers. In long term measurements, instrument repeatability (precision) may be affected by aging of the electronic and mechanical components resulting in a drift of the instrument readout [7].

The mechanical instruments like the level and theodolite can be easily tested and in some cases adjusted by an experienced senior surveyor in the field using procedures given in most good books on geodesy. The electronic level & theodolite can be tested but adjustment / repairs are not recommended except by a trained electronics technician.

The electronic distance measuring equipment is a different ball game all together. We need to have a proper baseline available to carry out the testing on regular basis and every so often the instrument need to go to proper service shop for checking the frequency drift etc. The recommended literature is “Guidelines for the Calibration and Testing of EDM Instruments” produced by Royal Institution of Chartered Surveyors, London.

Record / Log of testing, adjustment and calibration of all instruments used in deformation monitoring process is essential as back up reference material. The information should be well documented and available for review or reference.

9. ACCURACY STANDARDS

Accuracy is the degree of conformity with a standard or a measure of closeness to a true value.

Accuracy relates to the quality of the result obtained when compared to a standard. It is distinguished from precision which relates to the quality of the operation used to attain the result.

Precision is the degree of refinement in the performance of an operation (procedures and instrumentation) or in the statement of a result. The term precise also is applied, by custom, to methods and equipment used in attaining results of a high order of accuracy, such as precise yard rods [8].

Levelling

First Order

Class I 4mm Square Root of K

Class II 6mm Square Root of K

Second Order

8.4mm Square Root of K

Third Order Levelling:

12mm Square Root of K

(where K is distance in Kilometers)

Triangulation:

First Order

Triangle Closure; average not to exceed 1”

 Maximum not to exceed 3”

Probable error of computed distance 1:60,000 to 1:250,000

Second Order

Triangle Closure; average not exceed 3”

 Maximum not to exceed 5”

Probable error of computed distance 1:20,000 to 1:50,000

[8].

10. GLOBAL POSITIONING SYSTEM (GPS)

GPS as the name suggests is the technology for position fixation of points, it could be on the surface of the earth or in the air. It is the technology which has made it possible to make high accuracy spatial data easier to acquire in far less time than ever possible before through the conventional geodetic surveying techniques.

Differential GPS (DGPS) Techniques:

The idea behind all differential positioning is to correct bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal. DGPS is more accurate method.

This technology can achieve accuracy standard of $3\text{mm} + 0.5 \text{ ppm}$ that is if a baseline is 2 km long, an accuracy of $\pm 5\text{mm}$ (1:400,000) will be achievable. It is about as good as any achievable with modern electronic distance measuring (EDM) instruments. In doing angular measurements an error of 0.5 second of arc will produce a displacement of 5mm at a distance of 2 km.

In November 1992 the Tarbela baseline TA7 – TA8 with accepted slope distance value of 1006.814 m was measured with Leica GPS 200 and the slope distance came to 1006.8148m, an agreement of 1:1,258,000 which is excellent.

GPS has limitation that it can only be used where we have clear view to the sky such that a minimum of 4 satellites can be accessed forming good intersection.

11. CONCLUDING REMARKS

1. From project planning to execution, the surveyor's knowledge and judgments helps gain accurate, unbiased results. Precise measurements of movements of structures are now possible using new surveying techniques and analysis software. The precision and level of detail of information which can be extracted from a deformation survey allows improved modeling of structural stresses and possibly earlier prediction of failure.
2. Adequate deformation monitoring system is a must for the safety of dams. Only two large dams (Mangala & Tarbela) are well taken care of in this respect whereas others have been ignored.
3. In Pakistan we have many dams which fall under the classification of large dams and they need our urgent attention as far the deformation monitoring goes.
4. Deformation monitoring is a specialized task that requires devotion and research oriented temperament; therefore only professionals

trained in this aspect of geodetic surveying should be hired to carry out task.

:\awmir\lectures\deformation monitoring

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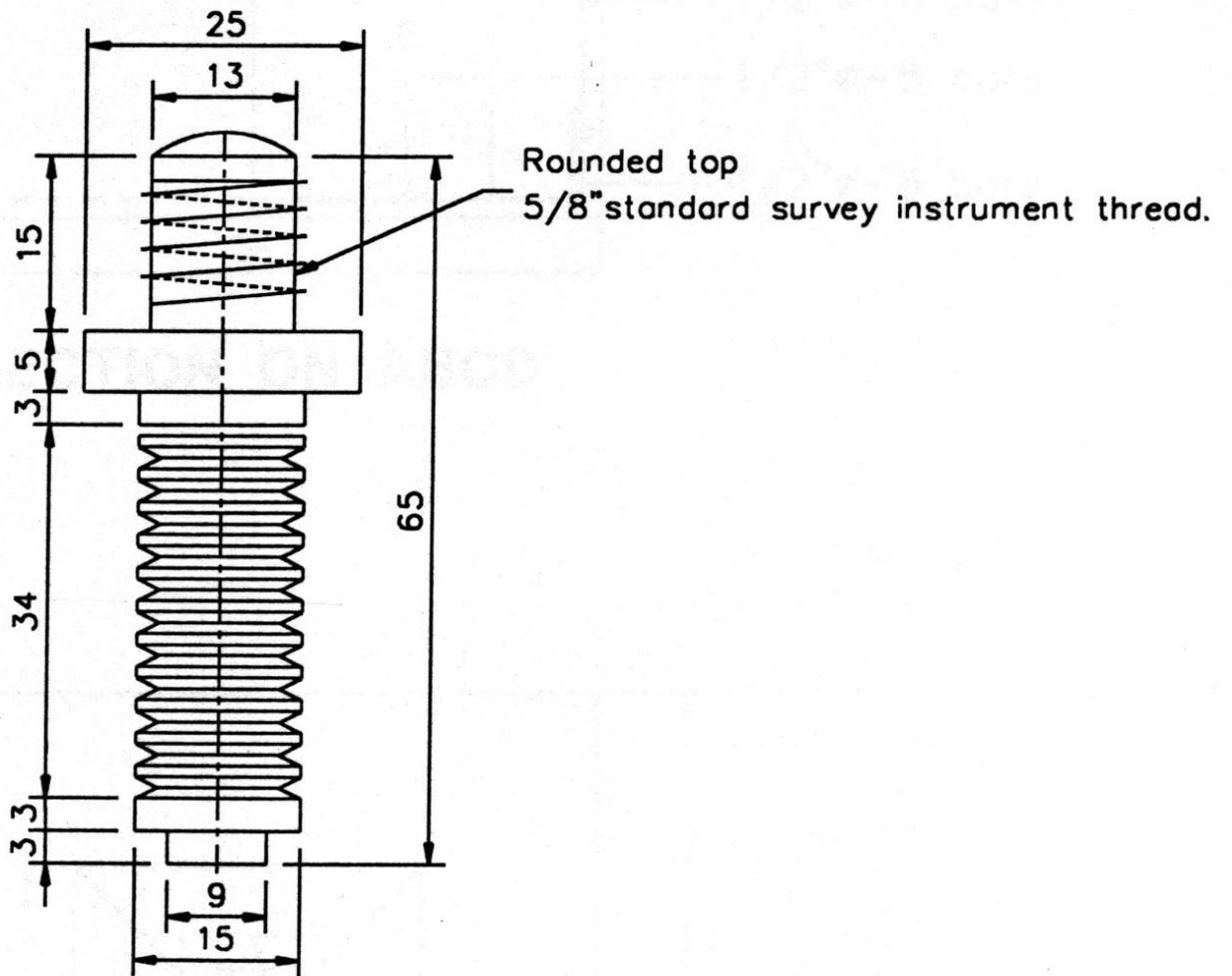
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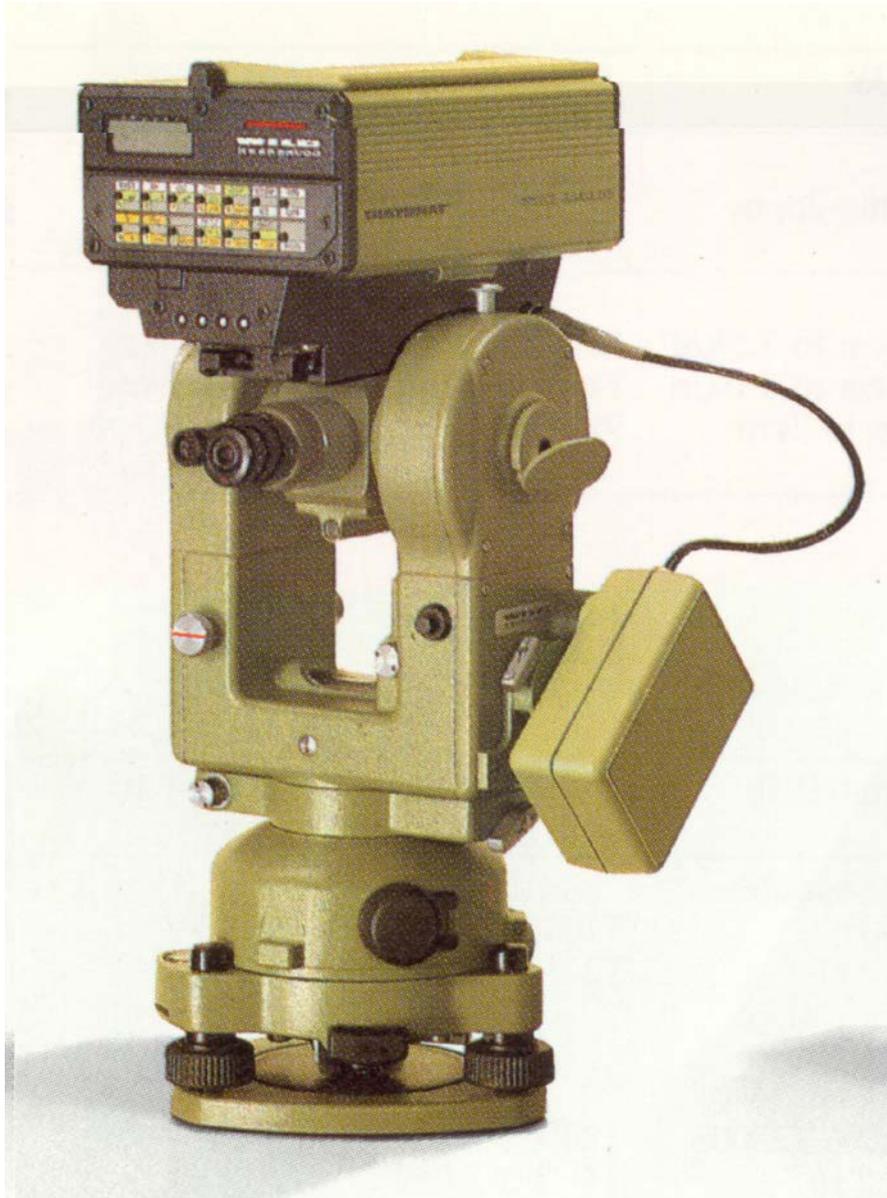






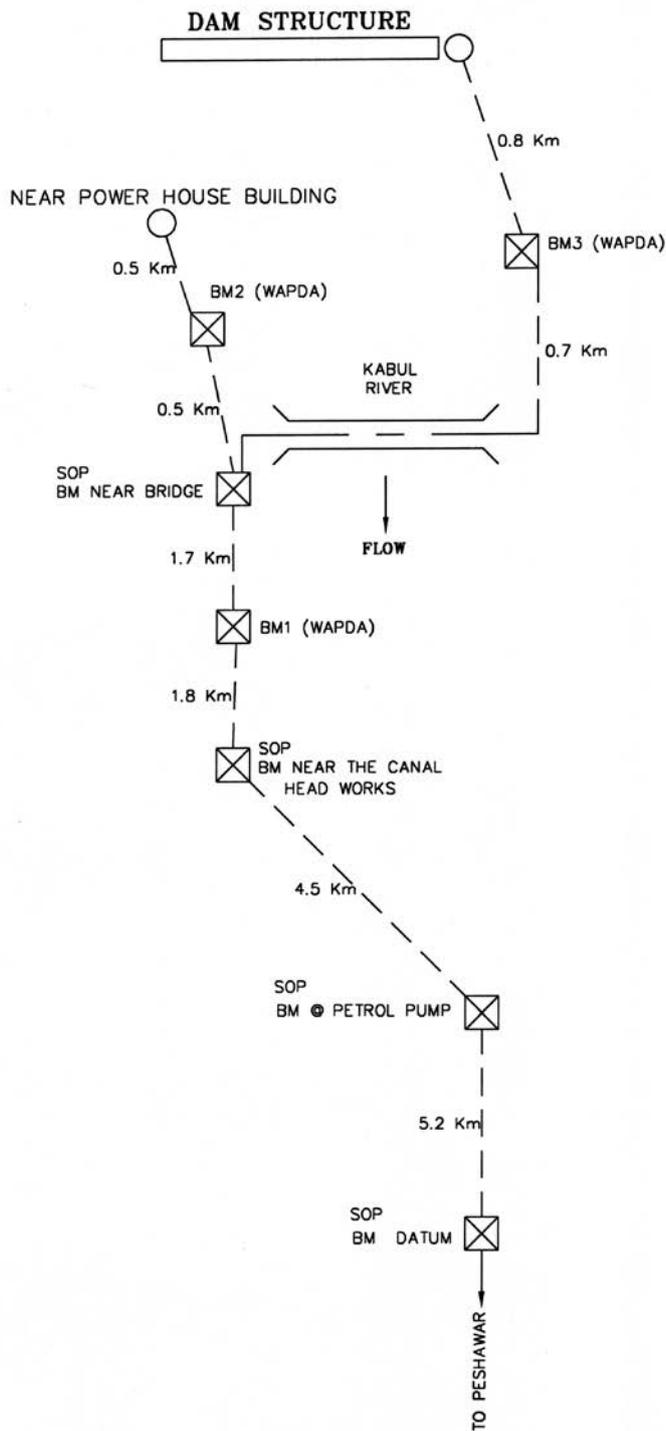
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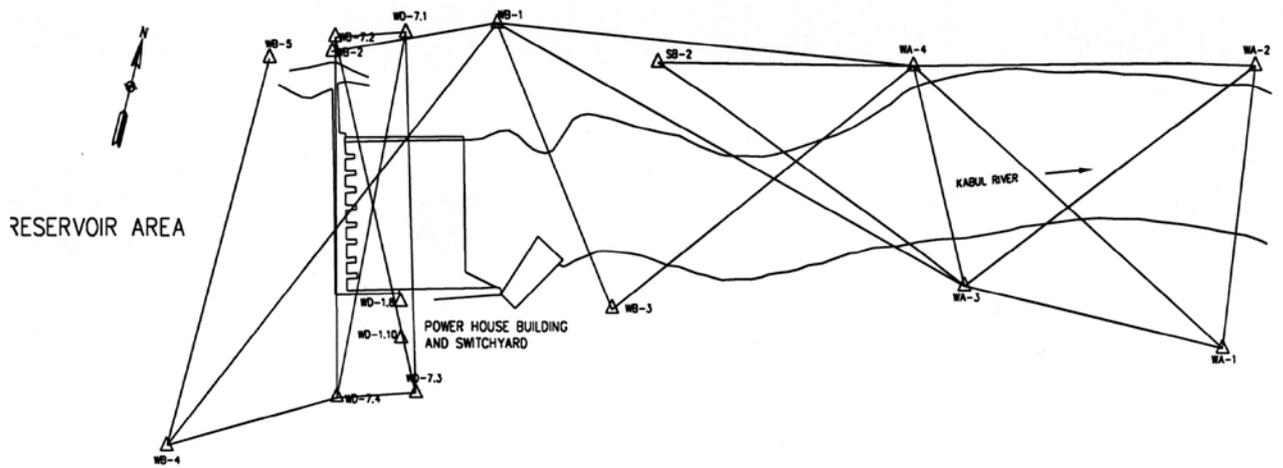


WARSAK DAM VERTICAL CONTROL SCHEMITIC DIAGRAM



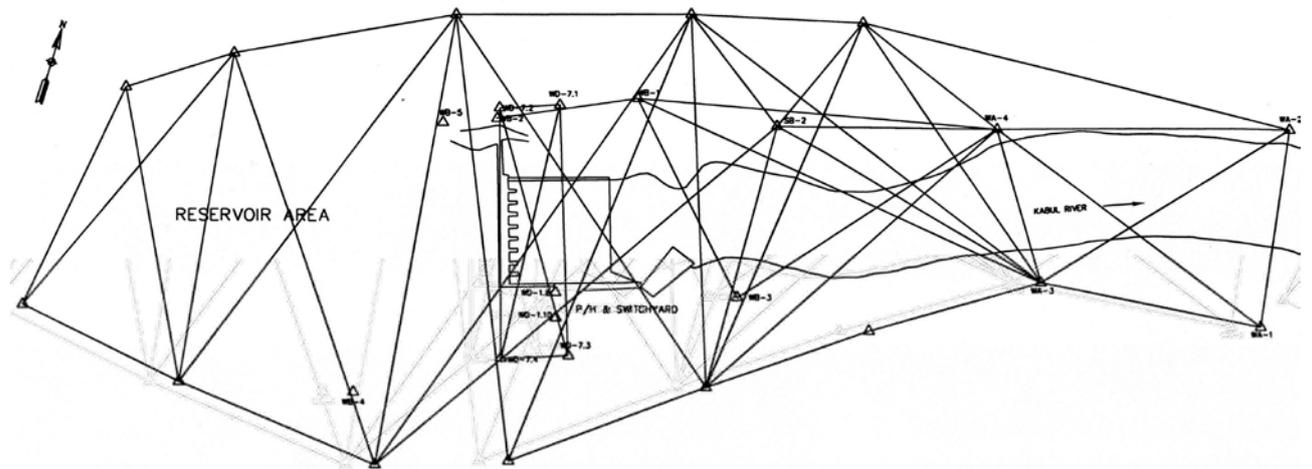
**NEP
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SURVEY & MAPPING
Lahore

Figure No. 1



WARSAK DAM
ORIGINAL SURVEY CONTROL NETWORK

Figure No. 2



WARSAK DAM
STRENGTHENING AND EXTENSION
OF SURVEY CONTROL NETWORK

Figure No. 3

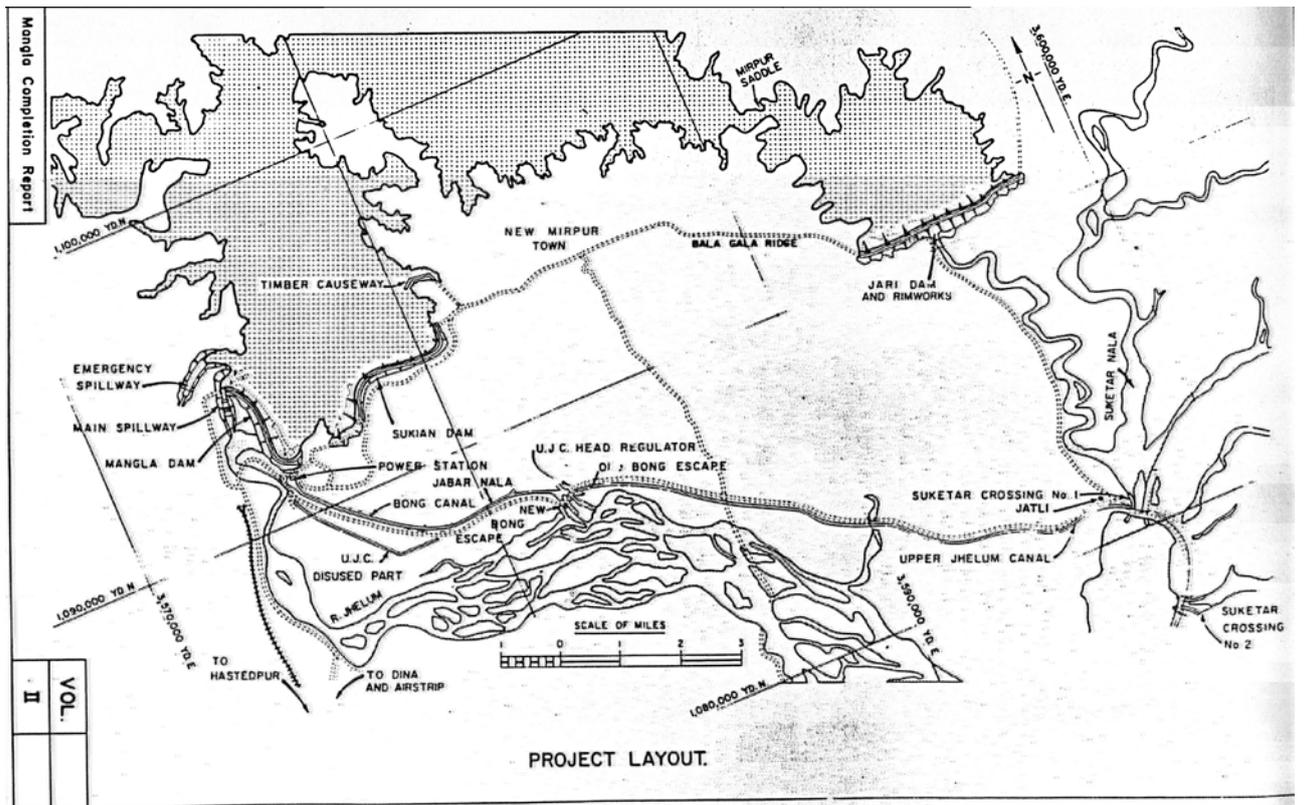
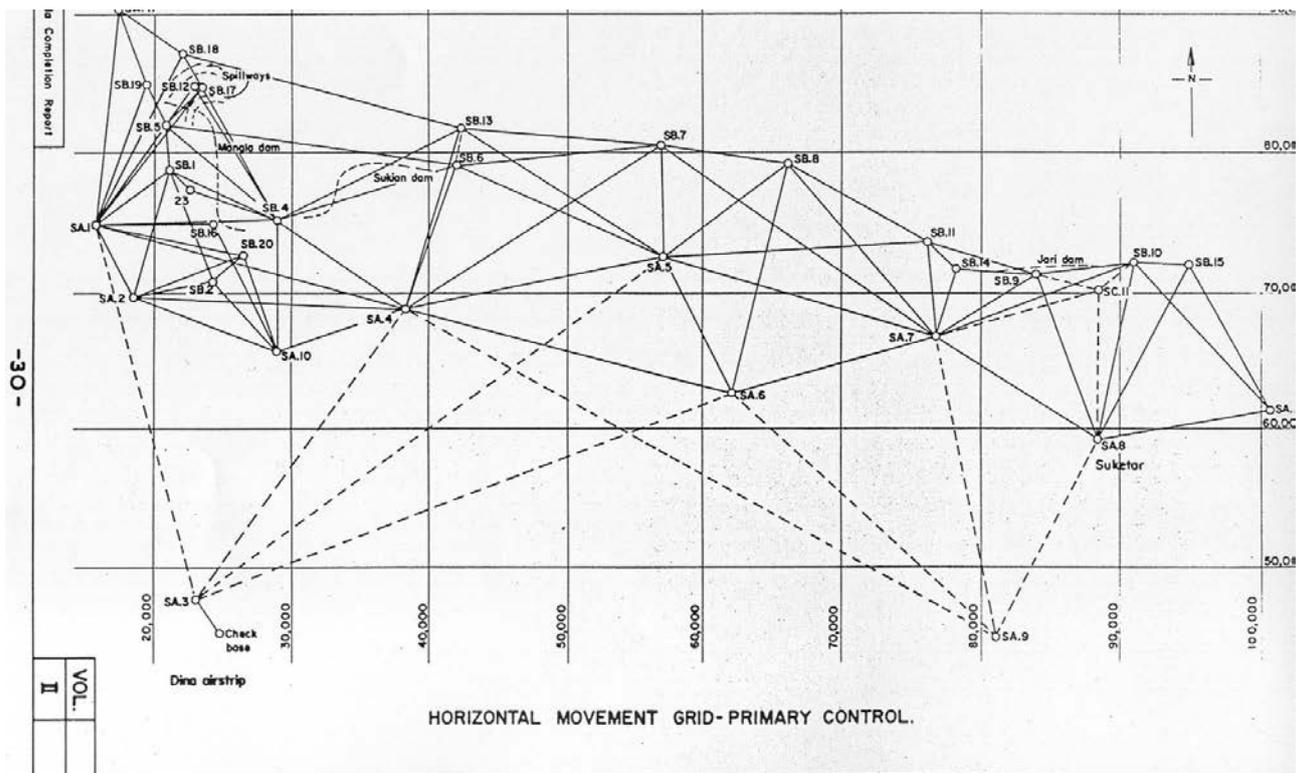
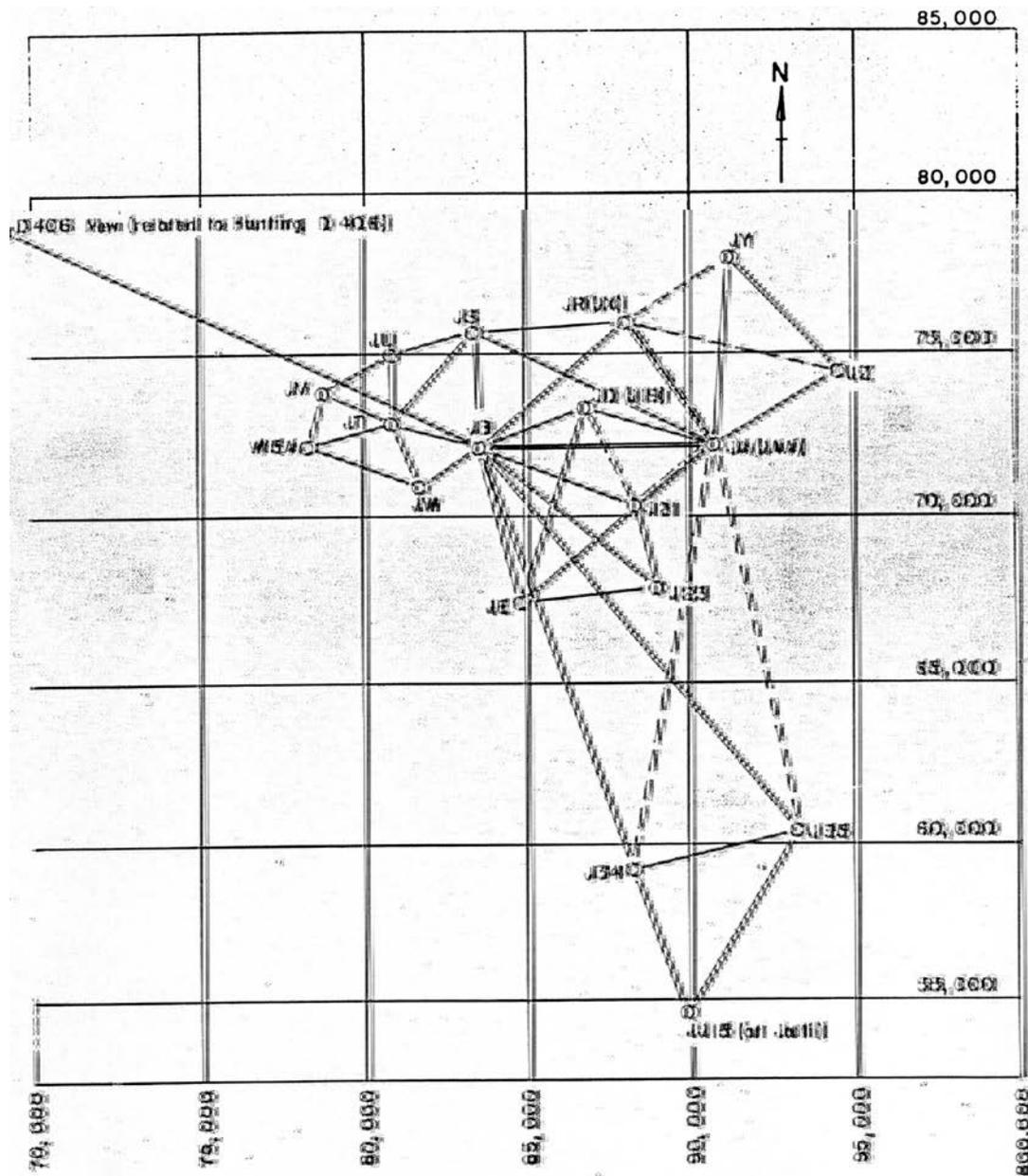


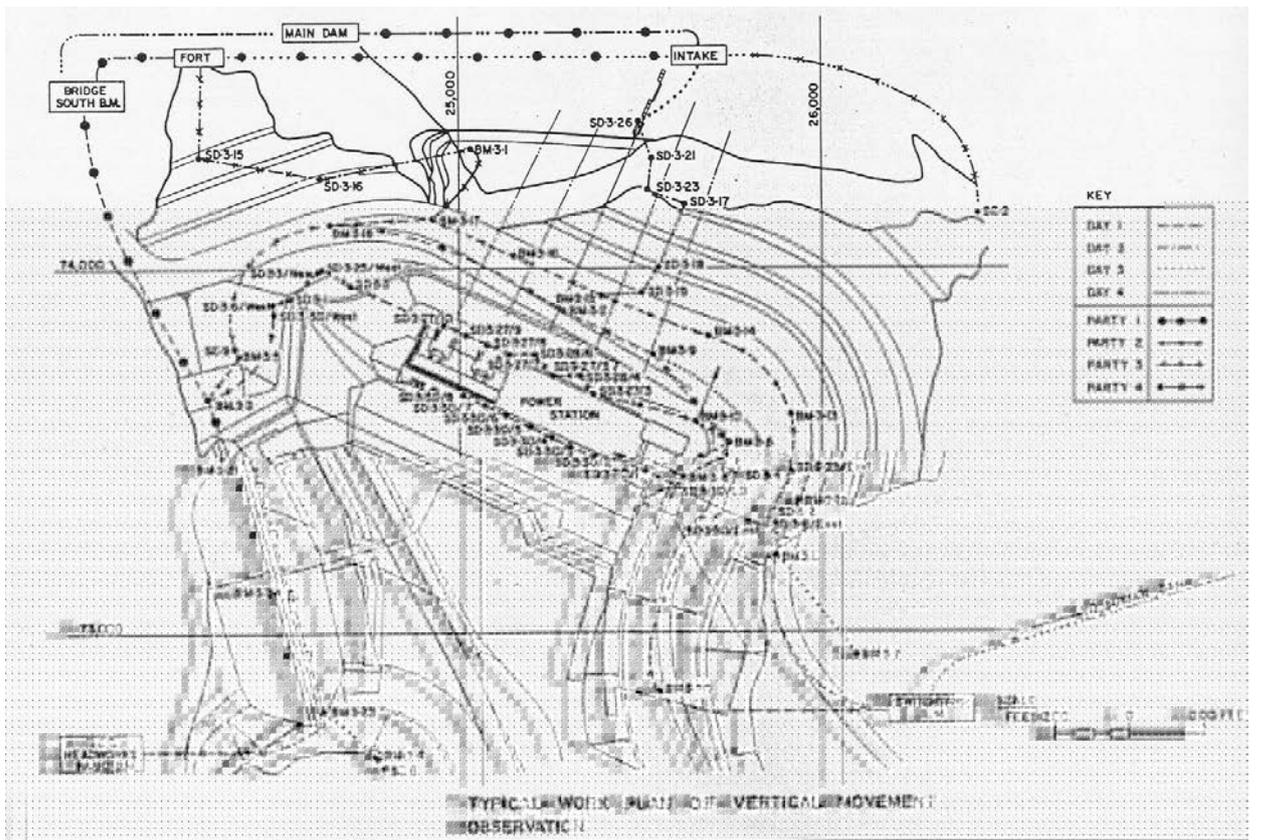
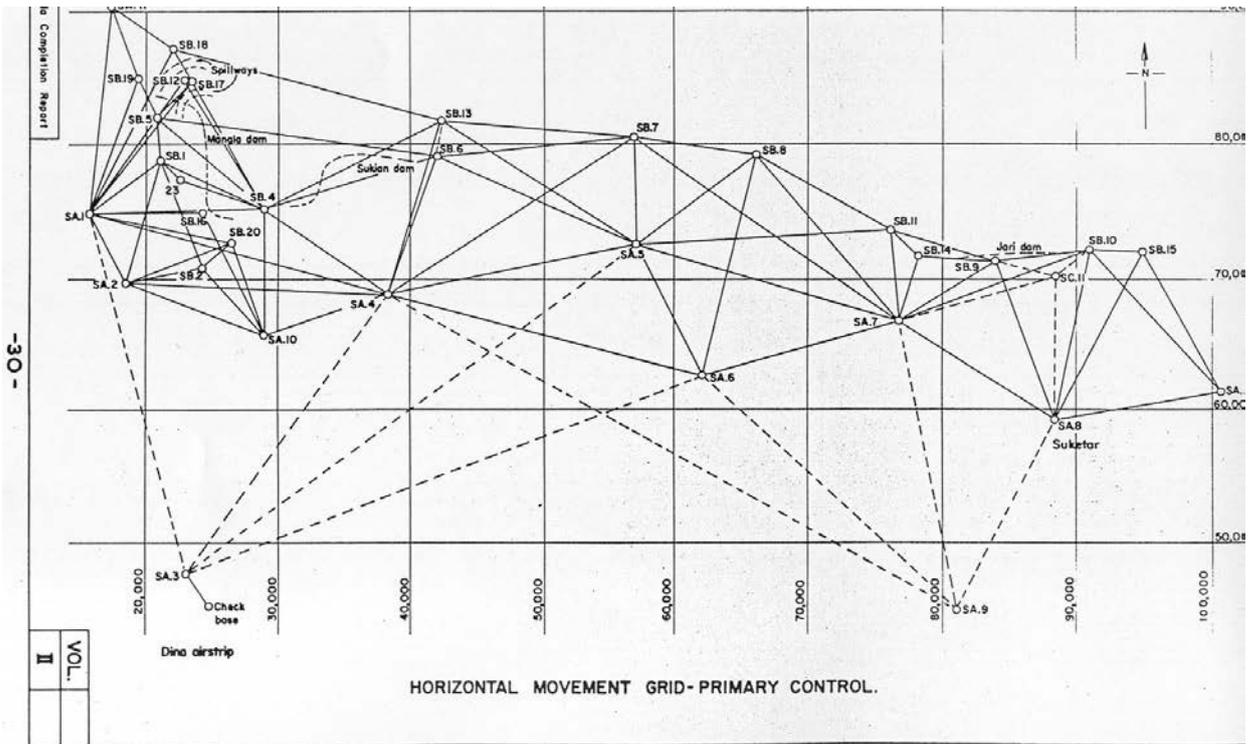
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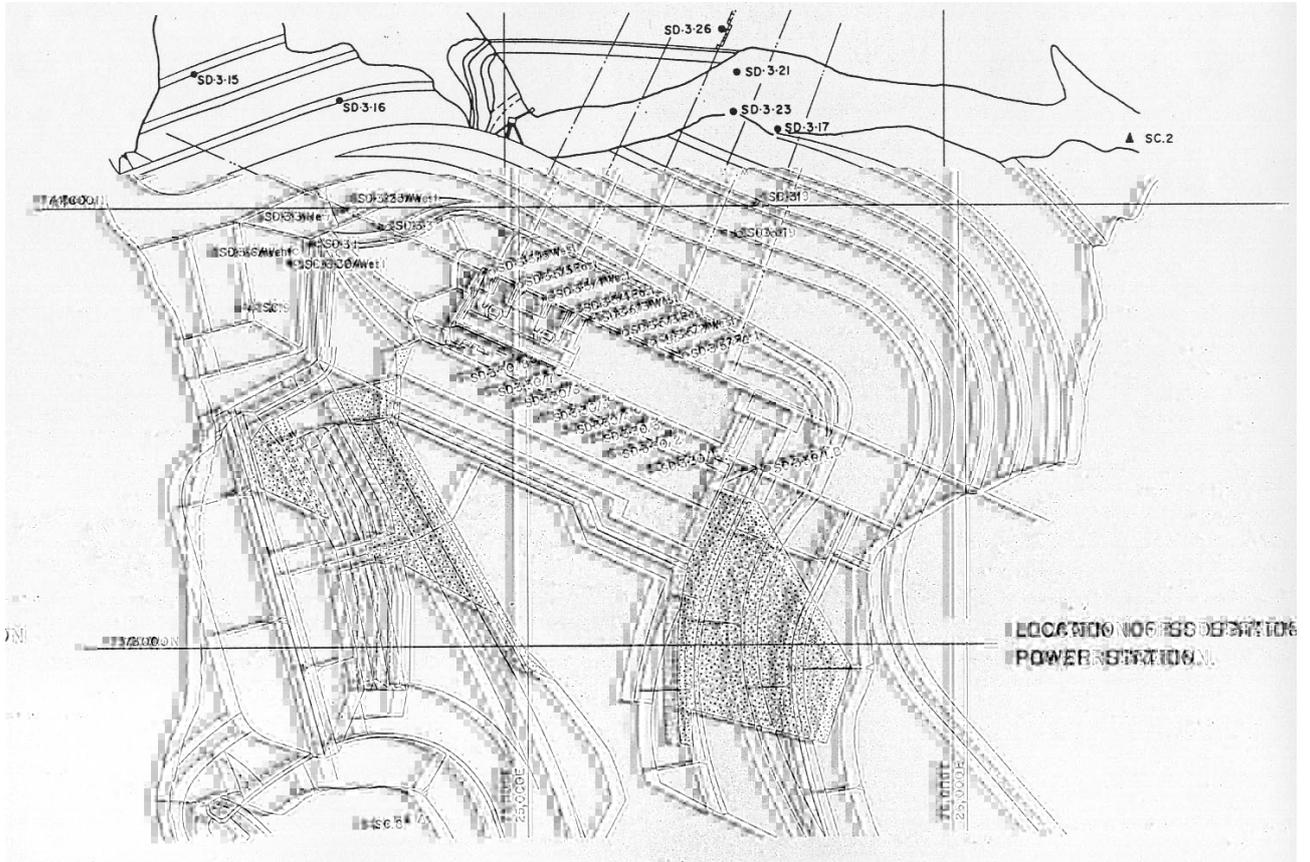


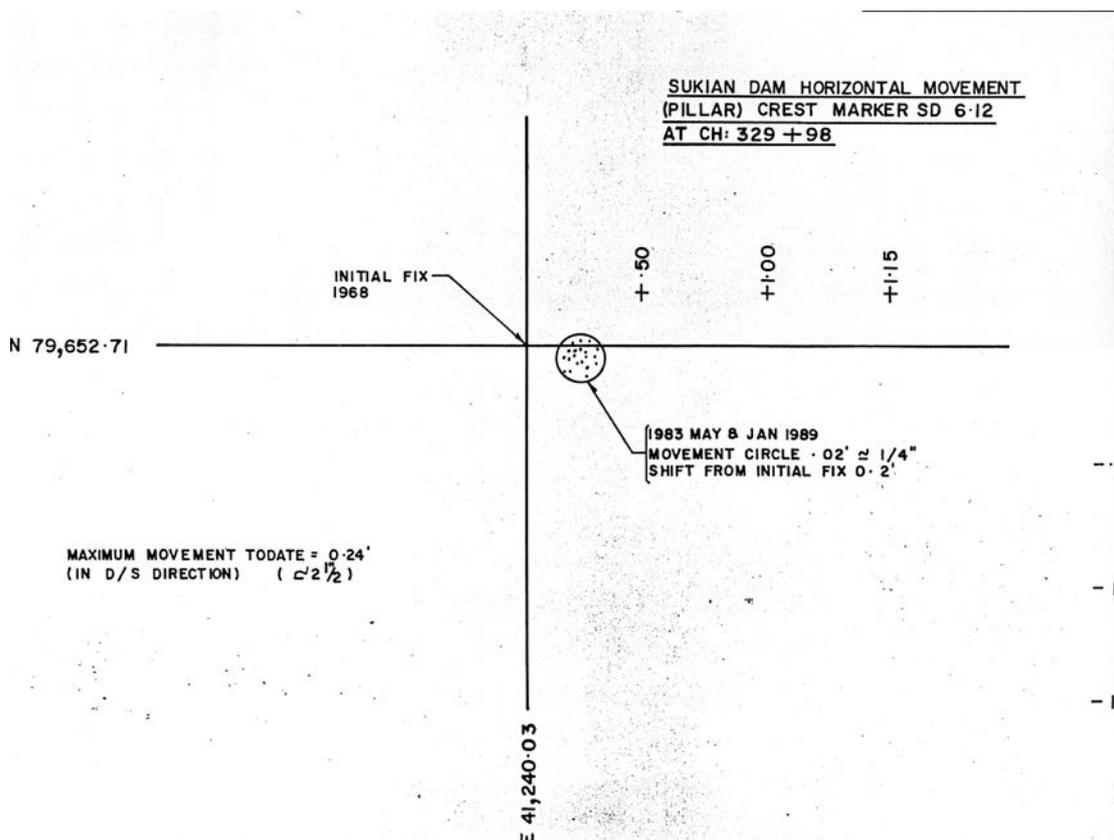
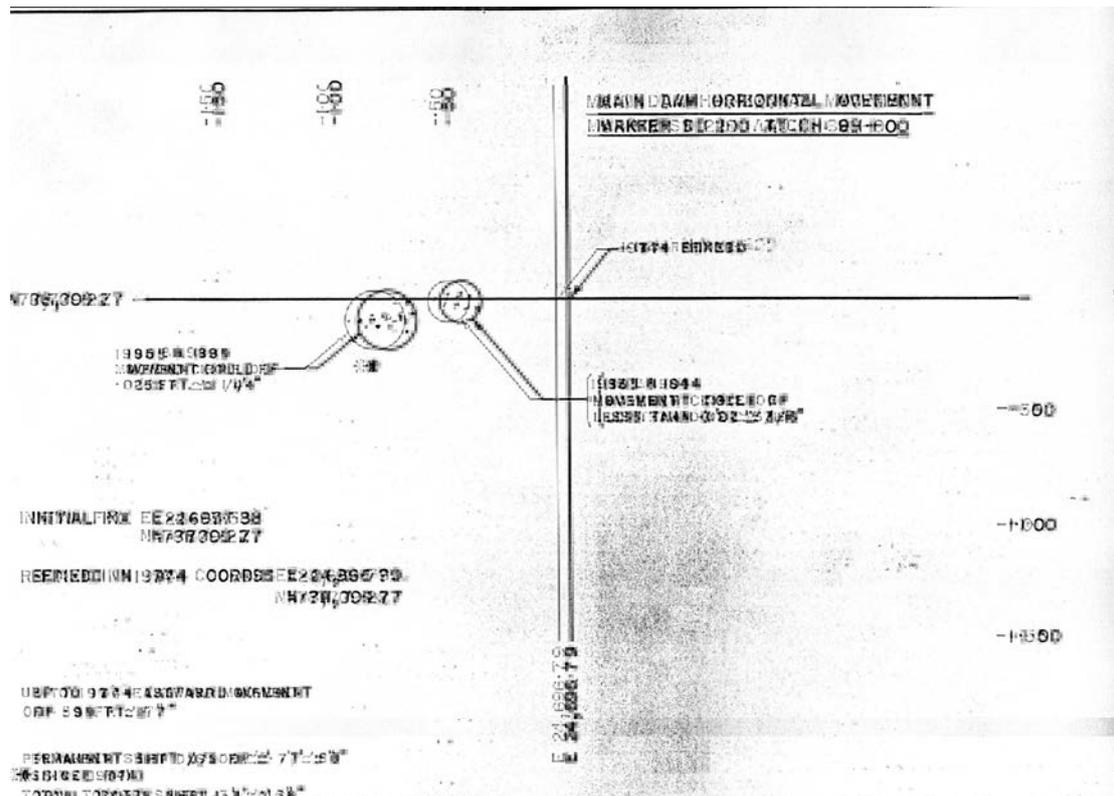


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JÄRNI COÖRDEEKTIOONIBE PÄRITÄVA PEALISE KONTROLLI







MAIN DAM VERTICAL MOVEMENT ON SD 2-9/12

@ CH. 86+35

13' U/S

SLOPE INDICATOR #

MAXIMUM SETTLEMENT TODATE = 4.79 FT.
DURING THE LAST 6 YEARS = 0.48 FT.
@ THE ANNUAL RATE OF 0.08 OR 1"

ELEV.

1233.643

.543

.443

.343

.243

.143

1233.043

12/82

1983

12/83

1984

12/84

1985

12/85

1986

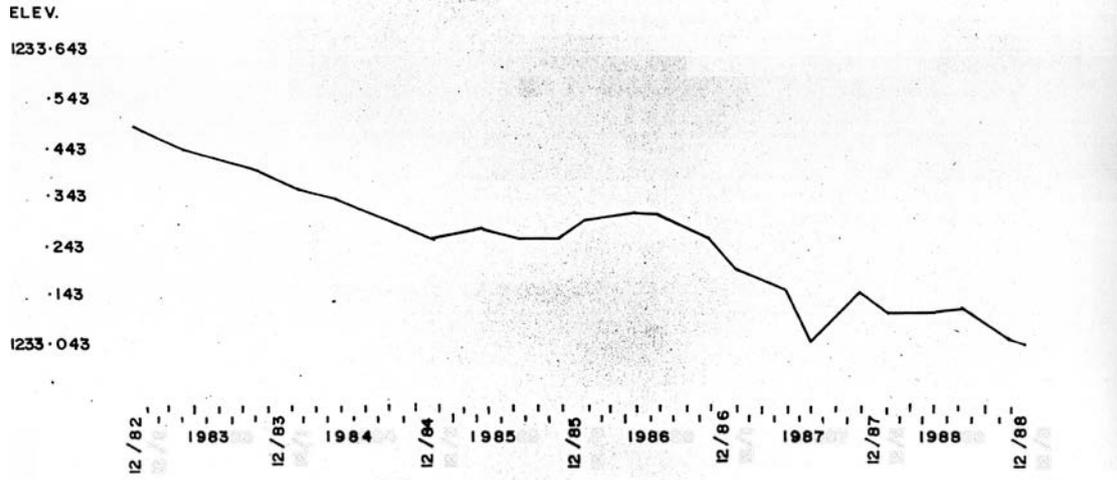
12/86

1987

12/87

1988

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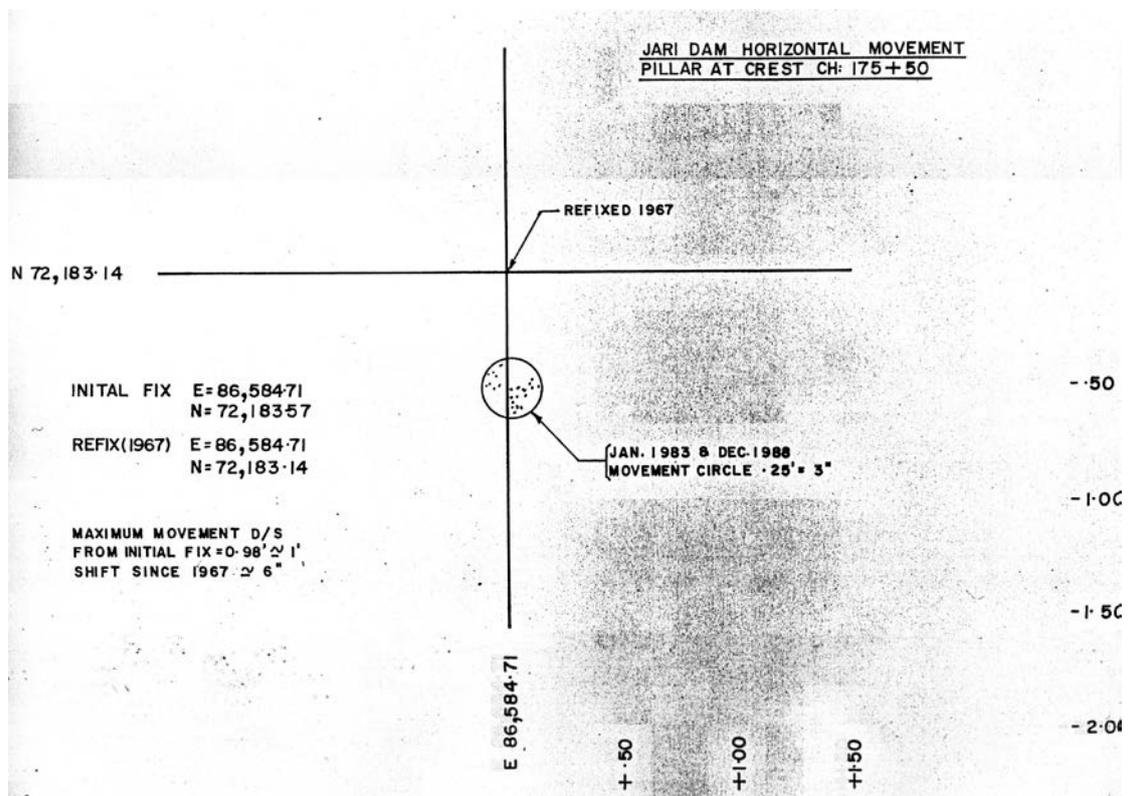


Figure No. 15

