# A STUDY OF EARTH DAM MODELS UNDER SHOCK LOADING

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## SYNOPSIS

Model tests on Ram Ganga Saddle dam, 66m high, were performed on a shock vibration table 5.0m x 2.8m to study its behaviour under simulated earthquake loading. Sections including in this study were those (i) with central clay core (ii) with inclined clay core and (iii) with no clay core. It was found that the section with inclined clay core exhibited greater resistance to horizontal shocks.

Response of this model was also studied analytically for excitation equal to that of El-centro earthquake (N-S component) of May 18, 1940, and it was compared with the response for the table motion. It was found that the table motion compared favourably with the earthquake motion expected at the site of the dam, taking into account the scale effect.

## INTRODUCTION

Design of earth dams in seismic areas is a problem of great importance to countries like India where several high earth and rock-fill dams, notably Obra 29m, Ram Ganga 122m, Kishau 267m, Tenughat 55m, Kothar 183m and P ong 100m are either under construction or are in the stage of planning. Work carried out in connection with these dams is proposed to be reported from time to time.

In an earlier work (1) the factors involved in the design of earth dams in seismic zones have been analysed including treatment of dam section as a shear structure and special features of their design. In another report (2), field tests carried out for the Ram Ganga Dam and test results on its models including variation of acceleration pattern with its height was presented. Behaviour of Earth Dam Models of Ram Ganga Saddle Dam under full and empty reservoir conditions were reported later (3). Method of Analysis of slopes and stability charts for earthquake conditions have also been reported (4,5,6) earlier.

In this paper results of salient tests done on Ramganga Saddle dam on 5m x 2.8m shock vibration table have been presented. Response

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of this model was evaluated for typical table motion and for N.S. component of El-centro earthquake. It was found the table motion represented the expected earthquake motion at the site reasonably well.

## EVALUATION OF MODEL STUDY

Model testing offers a very useful tool to study the qualitative behaviour of complex structures and also comparision of different designs of the same structure. Quantitatively, however, tests will give reliable results only of the scaling laws and requirements of similitude are properly met. Similitude requirements for testing small scale models of earth dams were first enunciated by Clough and Pritz (7) along with a few model test results. Seed and Clough (8) suggested that model studies might be utilized for (a) semi-quantitative determination of response of corresponding prototype and (b) increasing available knowledge of the mechanics of the response of dams to earthquake shocks. Ambraseys (9) raised a series of questions on the efficacy of any model tests on earth dams to studybtheir performance under earthquake loads. These problems may be summarised, in brief, as follows:-

(i) Problem of simulating comparable properties of model materials.

(ii) Problem of simulating comparable stress levels in models.

(iii) Problem of simulating earthquake motion in the laboratory.

No complete and definite solutions to the above stated problems are available at present. For that matter, analytical solutions based on elastic behaviour, assumed fixity of supports and other boundary conditions, assumed hydrodynamic behaviour of water fill, and not taking into account the change in soil properties due to the dynamic character of the forces applied leaves much to be desired. All the same, both methods need not be discarded altogether because they both help to arrive at several useful conclusions. It is proposed to describe here the results obtained on the experiences with model tests performed by the authors.

A model of the Ram Ganga dam which is proposed to be about 122m high was tested on a shock type vibration table. The scale ratio was 1/200. The damage pattern on the downstream face was similar to that of ONO dam Japan (10). Subsequently a number of models of Ram Ganga Saddle dam about 66m high were tested with scale ratio of 1/100 (3) (The dam has since been built taking into account the findings of these tests). The failure pattern was invariably repeated. The table motion was essentially perpendicular to the axis of the dam. The observed failure patterns along with that in ONO dam are shown in Figures 1,2 and 3.

This shows that shortcomings in simulation, as stated earlier, tend to compensate each other to a great extent, thereby producing a result a good deal similar to a proto-type test during an actual earthquake.

Secondly, if performance of different sections has to be studied, the models of these sections tested under similar shocks or motion will certainly give an idea of the relative performance of each section. In this case, the model may as well be considered to be a prototype of small height. This is again an important point which justifies model studies.

TESTS ON RAMGANGA SADDLE DAM

Three primary sections of Ram Ganga Saddle dam were tested on the shock vibration table, Figure 4. The properties of model and prototype materials are listed in Table 1.

A thin layer (about 3") of local clay was spread on the table to simulate impermeability of foundation under full reservoir condition. Table 2 shows the tests performed.

Deformation of all profiles after test was studied with respect to the original profile after a series of horizontal shocks were given to the model. It has been shown (3) that the damage suffered by the section without core under full reservoir conditions was the worst. Also deformations of section with central core were relatively bigger than those for the section with sloping core.

Taking into account the anticipated ground motion, the acceleration that has been adopted for design of Ram Ganga Saddle Dam is 12% g (15) uniformly acting over the full height.

Factor of safety for up-stream face ($F_s$) with respect to strength by the swedish slip circle method may be written as

$$F_s = \frac{\Sigma N \tan}{\Sigma T} + \frac{\Sigma c.l}{\Sigma T} \qquad \ldots (1)$$

where N = Normal component of weight of any slice

T = Tangential component of weight of any slice

l = Arc length of the lower boundary of the slice.

For the same factor of safety in the model and the prototype, both $\frac{\Sigma N \tan}{\Sigma T}$ and $\frac{\Sigma c.l}{\Sigma T}$ must individually have the same value both in the model as well as the prototype. Since 'N' and 'T' are components of weight both in the model and the prototype, and $\phi$ was comparable their ratio remains constant. For the other ratio to remain constant $c_m/c_p$ needs be $1/\lambda$ when $\lambda$ defines the scale ratio. Thus the cohesion in the model should have been 1/100 of the value in the prototype since the scale ratio was 1/100.Since cohesion was not scaled in this ratio (See Table 1), the intensity of shocks imparted to models were of larger intensity. If the entire failure surface passes through a material with the same cohesion in the model as in the prototype, the intensity of shocks needs be increased 100 times. However, if the cohesion of clay has been scaled by a certain factor and only a portion of the failure surface passes through the cohesive material, the intensity of shocks on the model needs be increased only proportionately. On this basis the intensity of shocks in the model was about 50 times the anticipated ground motion. This was done on the assumption that failure surface is circular and passes through the clay core and the shell. But test data (3) shows that such a surface does not develop. This is also substantiated for section with sloping core by analytical and experimental work of Sultan and Seed (12). It was, therefore, decided to test the U.S. shell only.

In order to study the stability of upstream shell only, two tests were performed. The intensity of shocks was as follows:- First 20 shocks of 0.12g intensity and remaining 180 of 0.50g intensity. The section did not experience any appreciable deformations for shocks of 0.12g. This indicates that the deformations of the model for these shocks were elastic. When subsequent shocks of 0.5g intensity were given, the model showed some pl stic deformations which were cumulative.

Figures 5 and 6 show the relative damage to the sections. The deformations in the section with sloping core are relatively smaller than those in the model with central core.

For testing sections to ultimate collapse, 100 blows of 5.6g intensit had been given with full reservoir condition. This is about 50 times the anticipated ground motion.

In section with central core the upstream sand started slumping with the first blow of 5.6g. A set of cracks also developed on the downstream crushed sand rock, after few blows. On subsequent shocks, the cracks windened during the impact and then subsequently closed. The depth of these increased by only very small amount with additional shocks, since most of the energy was utilized in movement of the mass of earth which has already started sliding. This was obvious from the widening of the existing cracks.

There were no cracks in the clay core itself, but it separated from the downstream shell material for about three fourths of its height. The clay was observed visibly vibrating separately from the shell for about one third of its height along ABC Figure 7. Since the clay core neither cracked nor slided there was no flow of water from the upstream to the downstream and no collapse of the model occured.

In Section with sloping core there was also slumping of upstream and cracks in the downstream slope. The separation of the clay core from the downstream shell took place to a very small extent and there was no visible relative vibrations in the top portion of the section as were observed in the test with central core. There was no damage to the clay core itself and therefore, no flow of water took place from the upstream to the downstream.

All the test data reported above and that reported earlier (3) shows that a sloping core section stands the simulated shocks better than the one with central core.

## STUDY OF RESPONSE OF A MODEL TREATING IT AS A PROTOTYPE

In order to study the response of the model to typical table motion and its relation to its behaviour under say El centro shock of May 18, 1940, the response of a model was evaluated in the two cases.

The period (T) of the model for the fundamental mode, considering the profile to be made up of homogeneous material, traingular in shape+ and resting on rigid foundations, was computed as follows, (1),

$$T = 4.30 \quad h\sqrt{\rho / E} \;, \qquad \ldots (2)$$

where $h$ = Height of model (2'),

= Density of soil = $\left( \frac{120 \text{ lbs/cft}}{32.2 \text{ ft/sec}} \right)$

$E$ = Modulus of elasticity of soil

$\rho = 1.4 \times 10^6 \text{ lbs/ft}^2$ (assumed)

which gives,

$T$ = 0.0140 sec for the fundamental mode.

Earth dam is a continuous system and possesses infinite degrees of freedom. Response of the model in each mode of vibration can be evaluated considering each mode independent of other and computing the participation factors. However, in this paper, response of the model in first mode of vibration only. has been considered. Treating the model as a single mass for this purpose the governing equation of motion is

$$\ddot{Z} + zp\xi\dot{z} + p z = \ddot{y}$$

where $z$ = relative displacement of the mass

$\xi$ = damping factor and

$p$ = natural circular frequency of the model

$\ddot{y}$ = ground acceleration

+ These are the assumptions on which the elastic analysis is based.

Using the input data '$\ddot{y}$' for the

(i) El-centro Earthquake of May 18, 1940

and (ii) Typical Motion of the table on which the model was tested in equation (3) the response of the dam was obtained. The data for the above motions is as follows:

a) <u>Elcentro Earthquake</u>

Period of Model T = 0.014 sec

Damping of Model = 10%, 15%, 20%

Peak in El centro = Actual (0.319447 g).

Duration of El Centro considered in these computations was 3.5592 sec. since the maximum spectral response was obtained within this duration.

b) <u>Table Motion</u>

The table motion record gave the following values

| Time sec | Horizontal acceleration (g) | Time sec | Horizontal acceleration (g) |
|---|---|---|---|
| 0 | +5.600 | 0.32 | -0.374 |
| 0.01 | -3.360 | 0.35 | 0.000 |
| 0.02 | +0.187 | 0.37 | +0.299 |
| 0.04 | -1.320 | 0.44 | -0.149 |
| 0.10 | +0.746 | 0.50 | +0.112 |
| 0.15 | 0.000 | 0.58 | -0.075 |
| 0.19 | -0.746 | 0.66 | +0.112 |
| 0.21 | 0.000 | 0.74 | 0.000 |
| 0.28 | +0.3731 | | |

The computed response is as follows:

| | Peak accn. g | Sd cm | Sv cm/sec | Sa |
|---|---|---|---|---|
| El centro ($\xi = 0.1$) | 0.32 | 0.0016 | 0.0937 | 0.32 g |
| Table Motion ($\xi = 0.1$) | 5.6 | 0.03808 | 12.936 | 8.12 g |

The acceleration response of the model is about 25 times that of the El Centro shock. Considering a multiplying factor of 1.35 for the Housner's standard acceleration spectrum, which is reasonable for the Ram Ganga Dam site, the table motion does reproduce the characteristics of actual ground shock as reflected by the two responses. It is, therefore, expected that the prototype should behave as anticipated by the model tests if an earthquake of about half the intensity of El Centro were to occur.

Prototype tests on the Saddle dam which has since been constructed are being planned at present (1968) and their results would be reported later.

## CONCLUSIONS

The following conclusion may be drawn from the investigations reported in this paper:-

1. Sloping core dam exhibits superior behaviour during shock loading as compared to central core dam.

2. The table motion reproduces characteristics of typical actual ground movements such that the resulting damage as well as the response of the dams are comparable in the two cases.

Further work on correlation of model and prototype behaviour is under progress at the School.

## ACKNOWLEDGEMENT

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## REFERENCES

1. Krishna, J. "Earthquake Resistant Design of Earth Dams", Proceedings, Second Symposium on Earthquake Engineering, Roorkee, Nov. 1962, pp. 22-40.

2. Krishna, J. and S. Prakash, "Earth Dams Subjected to Earthquakes", Proc. III WCEE, New Zealand, Jan-Feb 1965, Vol.I, pp. 83-95.

3. Krishna, J. and S. Prakash, "Behaviour of Earth Dam Models Under Seismic Loading", Proc. Third Symposium on Earthquake Engineering, Roorkee, Nov. 1966, Vol.II, pp. 1-9.

4. Prakash, S. "Seismic Stability Analysis of Earthen Embankments" Paper presented at Annual Research Session, Central Board of Irrigation and Power, Srinagar, June 1966. Reprinted in Viswa-karma, Culcutta, April 1968.

5. Prakash, S., S. Saran and P. Raj "A Method of Seismic Stability Analysis of Homogeneous Slopes", Proc. Symposium on Earth and Rockfill Dams, Talwara Oct. 1968 (Under publication).

6. Prakash, S., S. Saran and P. Raj, "Seismic Stability Analysis of Homogeneous Slopes", Papar Submitted for Seventh International Conf. on Soil Mech. and Found. Engg. Mexico, Aug. 1969.

7. Clough, R.W. and D. Pirtz, "Earthquake Resistance of Rock Fill Dams", Trans. ASCE, Vol. 123, 1968.

8. Seed, H.B., and R.W. Clough "Earthquake Resistance of Sloping Core Dams", Proc. ASCE, Soil Mech. and Foundations Dn., Feb. 1963, 209-42.

9. Ambraseys, N.N., "Discussion on 2", Proc. III WCEE, N ew Zealand Jan.-Feb. 1965, Vol.I, pp. 93-95.

10. Earthquake Resistant Design for Civil Engineering Structures, Earth Structures and Foundations in Japan", Proc. Japan Society of Civil Engineers 1960, p.11 and Table 1 and 2.

11. Krishna, J., and S. Prakash, "Final Report on Seismic Stability of Ram Ganga Dam", Earthquake Engineering Studies, Sept. 1967.

12. Sultan, H.A., and H.B. Seed, "Stability of Sloping Core Earth Dams", Proc. ASCE, Soil M ech. and Found. Dn. July 1967, pp. 45-67.

TABLE 1

(a) PROPERTIES OF PROTOTYPE MATERIALS

| Type of Soil | $\gamma_d$ lbs/cft | C lbs/sft | degrees | Remarks |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Crushed Sand Rock | 113 | 1500 | 32 | Consolidated undrained test |
| Clay Shale | 116 | 2000 | 20 | |
| River Bed Material | 110 | 0 | 38 | Direct Shear Test |

(b) PROPERTIES OF MODEL MATERIALS

| Particulars of Section | Crushed Sand Rock (D.S. face) | | Clay | River Bed Material (U.S. face) |
|---|---|---|---|---|
| | C + | $\phi$ + | C ++ | (dry) |
| 1 | 2 | 3 | 4 | 5 |
| With no clay core | 700 | $15^o$ | - | $40.5^o$ |
| With central core | 700 | $15.5^o$ | 1550 | 40.5 |
| With sloping core | 720 | $15^o$ | 1500 | 39.5 |

+ Consolidated Quick Test, ++ Unconfined Compression Test

TABLE 2

PARTICULARS OF MODEL TESTS ON RAMGANGA SADDLE DAM

| Serial No. | Particulars of Section | Loading conditions for tests | |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1. | No clay core | Dry Reservoir | Full Reservoir |
| 2. | Central clay core | Dry Reservoir | Full Reservoir |
| 3. | Sloping clay core | Dry Reservoir | Full Reservoir |
| 4. | Central core ) | Full Reservoir. Study of U/S shell only | Full Reservoir. Tested to failure |
| 5. | Sloping core ) | | |

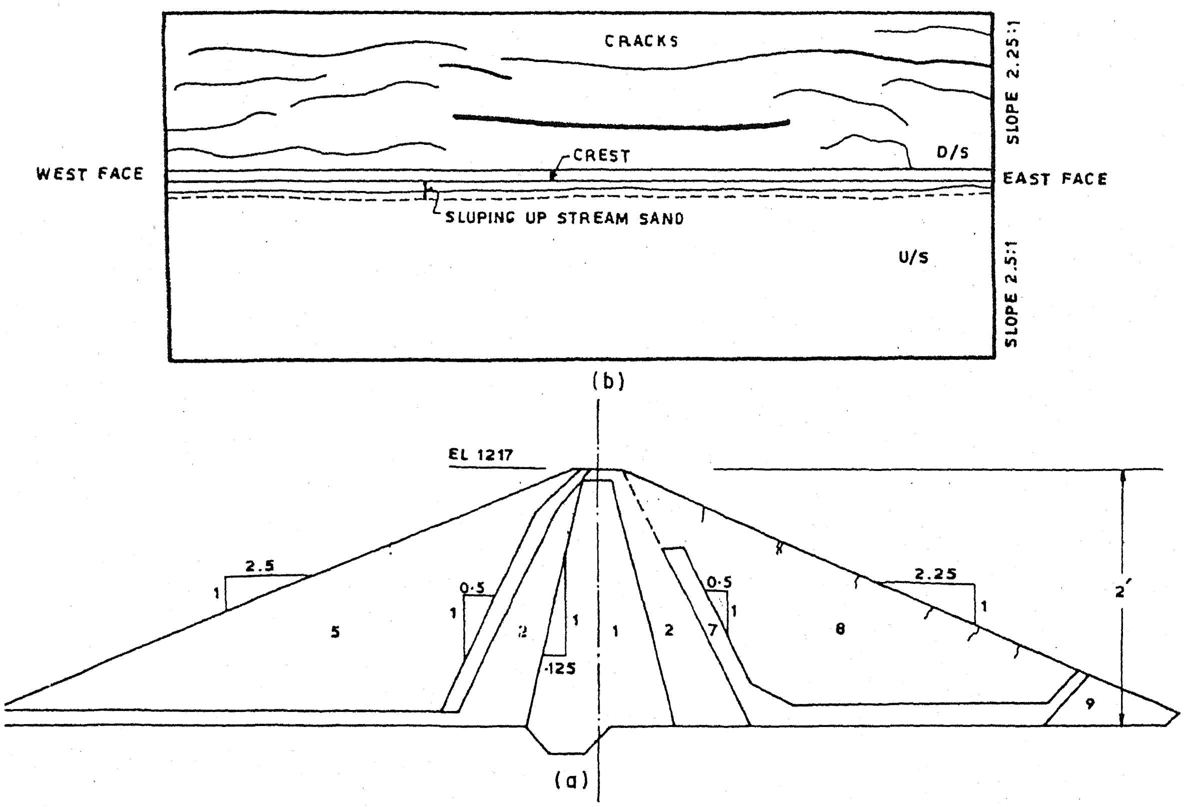
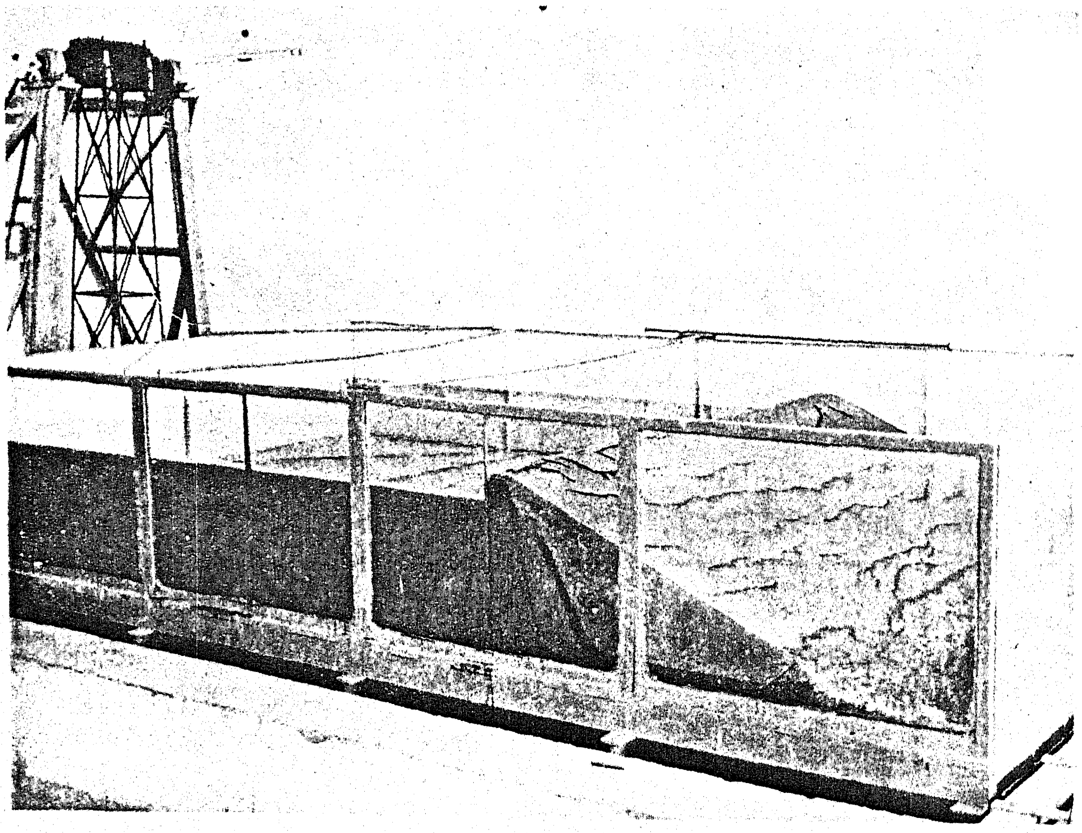



FIG. 1 -TYPICAL CRACK PATTERN ON THE FACES OF A MODEL WITH CENTRAL CORE



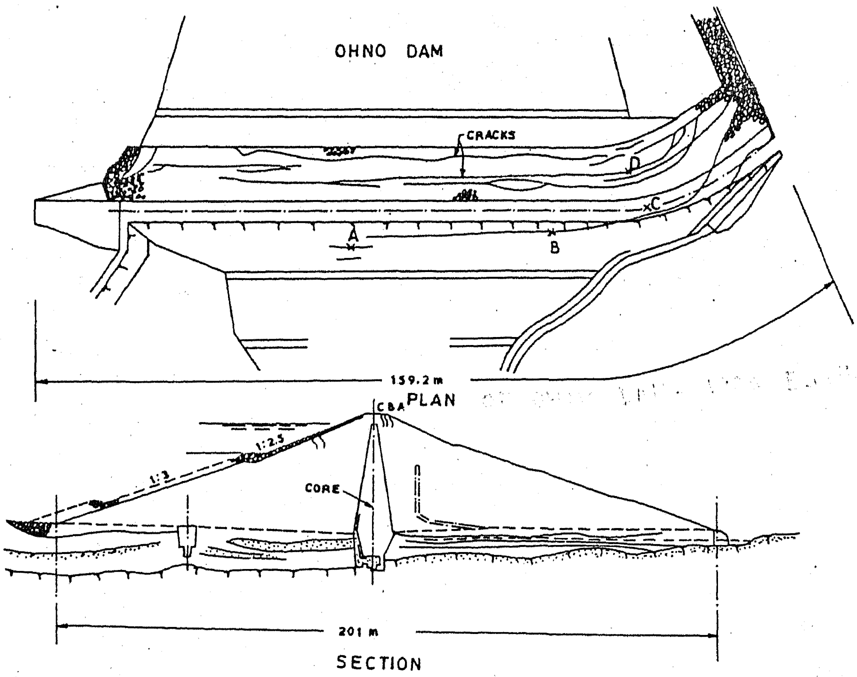



FIG. 3 – DAMAGE TO OHNO DAM-1923 EARTHQUAKE

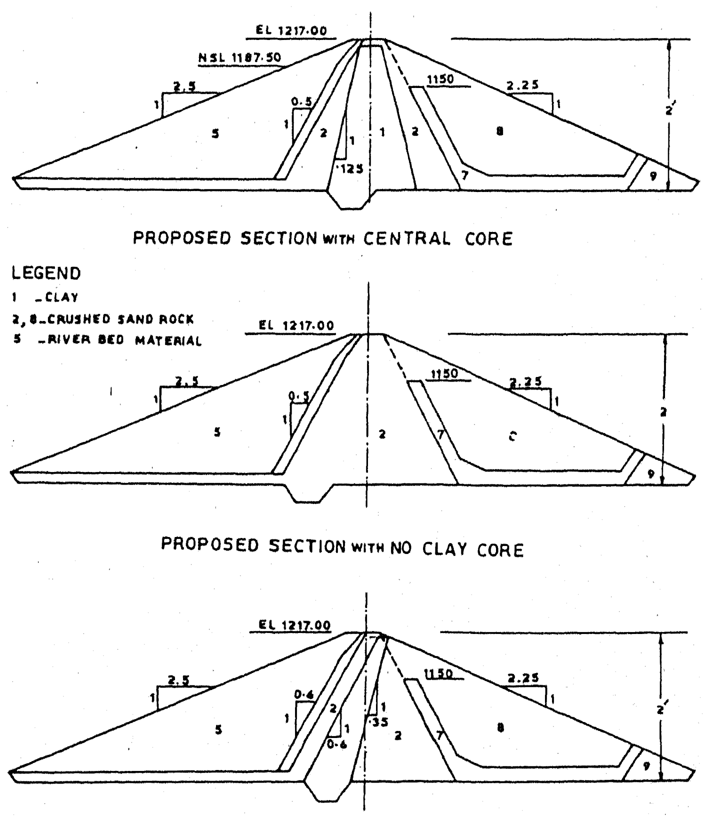



FIG. 4 – SECTIONS OF RAMGANGA SADDLE DAM

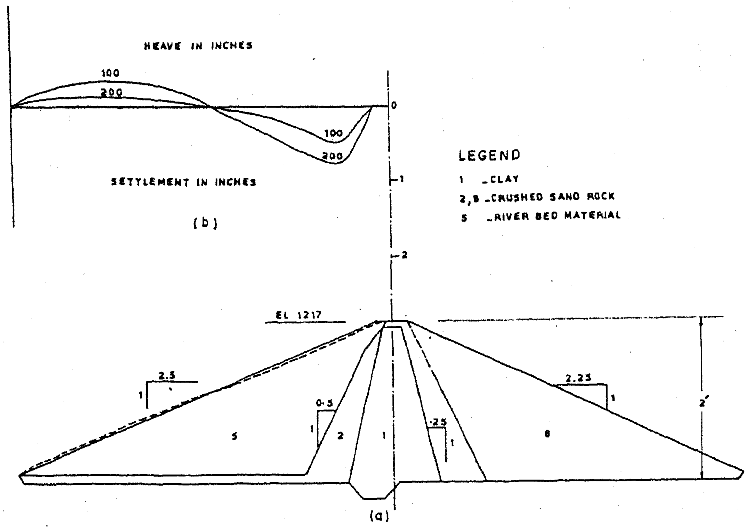



FIG. 5 _CENTRAL CORE SECTION TEST FOR U/S STABILITY FULL RESERVOIR

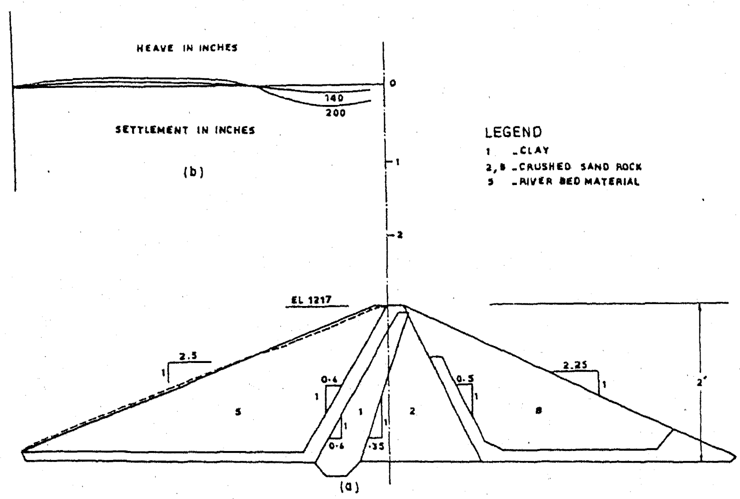



FIG. 6 _ INCLINED CORE SECTION TEST FOR U/S STABILITY-FULL RESERVOIR

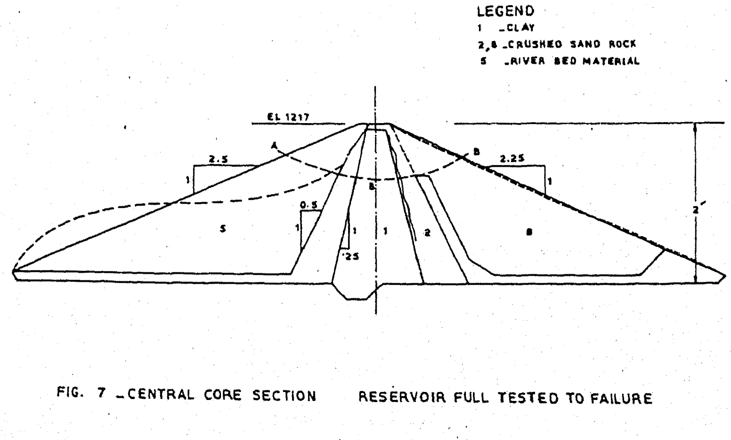



FIG. 7 _CENTRAL CORE SECTION RESERVOIR FULL TESTED TO FAILURE