BLAST TESTS AT TENUGHAT DAM SITE

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SYNOPSIS

Tenughat dam site, Bihar, India is likely to be subjected to earthquakes. Blast tests were carried out at the site, and laboratory tests were conducted on a horizontal vibration table at the School of Earthquake Research and Training, Rookee to ascertain the suitability of the Tenughat sand to withstand the anticipated ground shock without liquefaction and excessive settlement. Surface acceleration, pore pressure and surface settlement were measured in the field with distance from each blast point, and the maximum settlement and acceleration occurring in each case were found by extrapolation to the point of detonation. The field data obtained were assumed to be for a single cycle of loading and the effect of number of cycles was detemined from laboratory tests. The possibility of liquefaction is discussed, and the total settlement expected in the lifetime of the dam has been estimated by correlation of the field and laboratory data.

INTRODUCTION

Tenughat Dam site is on the Damodar River near East Bokaro coal fields, Hazaribagh District, Bihar State, India. The site is situated close to the southern margin of the coal fields. The area has experienced strong ground motion as a result of seismic activity in the neighbouring Bihar, Bengal and Assam regions. The basin feels the fringe effects of earthquakes which originate in the seismic zone about 240 km to the north, but this region by itself is not seismically active. A seismic coefficient of 0.1 *g* has been adopted for the design of the dam, although the peak ground acceleration may be many times this value.

An earth dam about 55 m high is proposed on this river. A loose sand deposit exists in the bed of the river to a depth of about 15 m. It was, therefore, necessary to ascertain the suitability of this sand to withstand the anticipated ground shock without undergoing liquefaction and excessive settlement.

Blast tests were carried out at the site in the bed of the river earmarked for the dam. Special gelatin (80%) was installed at a 6 m depth in cased boreholes. Each hole was filled with sand and the casing withdrawn before

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blasting. Both horizontal and vertical surface accelerations were measured at various distances from the point of detonation. The surface settlement and pore pressures at depths of 3 m, 6 m and 9 m were also observed with distance from the blast point. The possibility of liquefaction, and the total settlement expected in the life time of the dam under the expected ground shock, have been estimated from the field and laboratory data. Detailed laboratory tests were also performed on this sand and the results have been presented elsewhere (PRAKASH and GUPTA, 1968).

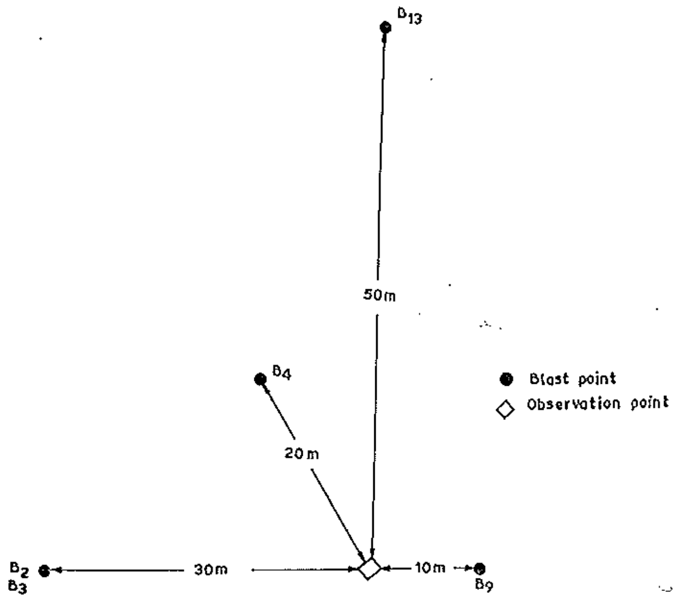

Fig. 1. Site layout for blasting tests.

DETAILS OF TESTS

Figure 1 shows a sketch of the layout of the test site. In all cases the depth of charge was 6 m, the amount of charge was 1 kg and the depth of the acceleration pick-up was 20 cm; the distances of these pick-ups from the blast points are indicated in Table 1, which also shows the measured horizontal and vertical accelerations. In tests *B2* and *B3*, the charges were fired from the same location at an interval of one day. Figure 2 shows a typical acceleration record (for blast hole *B13*).

Table 1. Measured horizontal and vertical accelerations

Blast No.	Distance of Acceleration Pick-ups (m)	Horizontal Acceleration, (*g*)	Vertical Acceleration, (*g*)
B2	30	0.182	0.258
B3	30	0.156	0.372
B4	20	0.262	1.10
B9	10	0.70	1.880
B13	50	0.0645	0.168

Settlements of the ground surface were recorded on settlement plates embedded at shallow depths. The pore pressure rises were observed on improvised piezometers over a predetermined grid around each blast point.

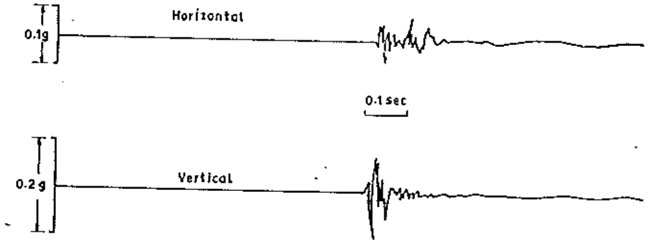

Fig. 2. Typical acceleration records (blast point *B13*).

ANALYSIS OF DATA

Liquefaction

Figure 3 is a plot of distance against the ratio of pore pressure and initial effective stress. For complete liquefaction, this ratio should be unity (KRISHNA et al, 1967). The observed values are considerably less than unity, indicating that complete liquefaction did not occur. Similar conclusions were also arrived at on the basis of laboratory tests (PRAKASH and GUPTA, 1968).

Settlements

Figure 4 is a plot of distance against surface settlement for the 1 kg charges placed at a 6 m depth. The maximum settlement, when extrapolated to the blast point, is 19 cm. Assuming that the zone of influence of this blast below the blast point extends to a depth of one third of the blast, we get

$$\text{settlement} = \frac{19}{(1+1/3)\,6 \times 100} = 2.4\%$$

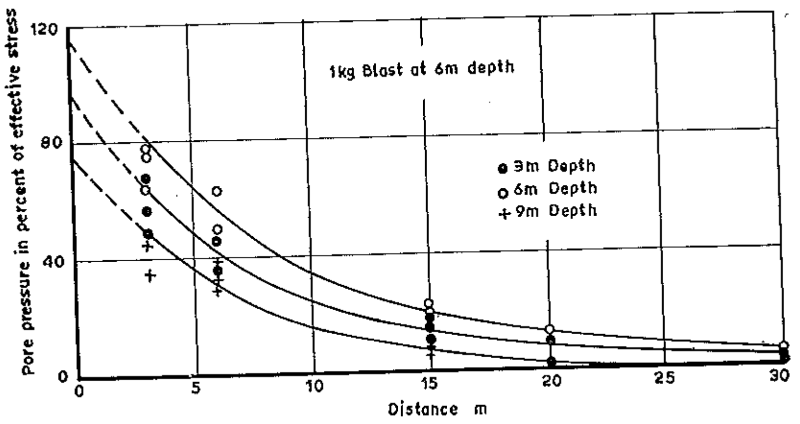

Fig. 3. Pore pressures developed as a function of distance from blast point.

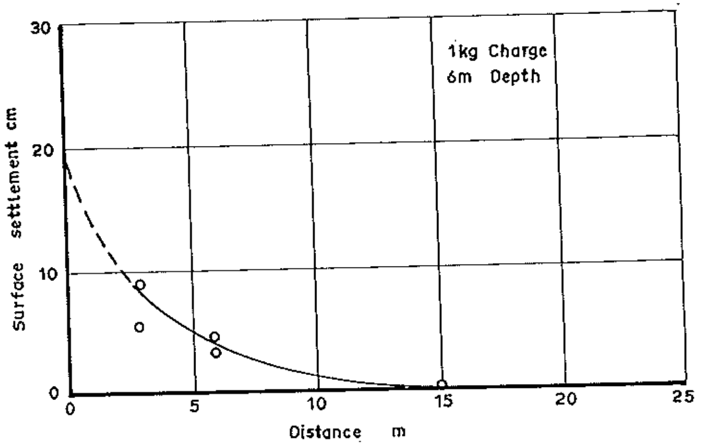

Fig. 4. Surface settlement as a function of distance from blast point.

Figure 5 shows acceleration plotted against distance for the tests. In general, the vertical acceleration is higher than the horizontal acceleration and the difference decreases as the distance of the observation point from

the blast point increases. This is because the angle of emergence of waves at short distances from the blast point deviate slightly from the vertical; the vertical acceleration of the ground motion is, consequently, higher than the horizontal acceleration. With increasing distance from the blast point, the difference between the horizontal and vertical accelerations gradually diminishes. The curves given in Fig. 5 are extrapolated to the blast point for the estimation of the accelerations at the blast point. The settlements shown in Fig. 4 occurred when the horizontal and vertical surface accelerations (Fig. 5) at the blast point were approximately 1.425 *g* and 2.90 *g* respectively.

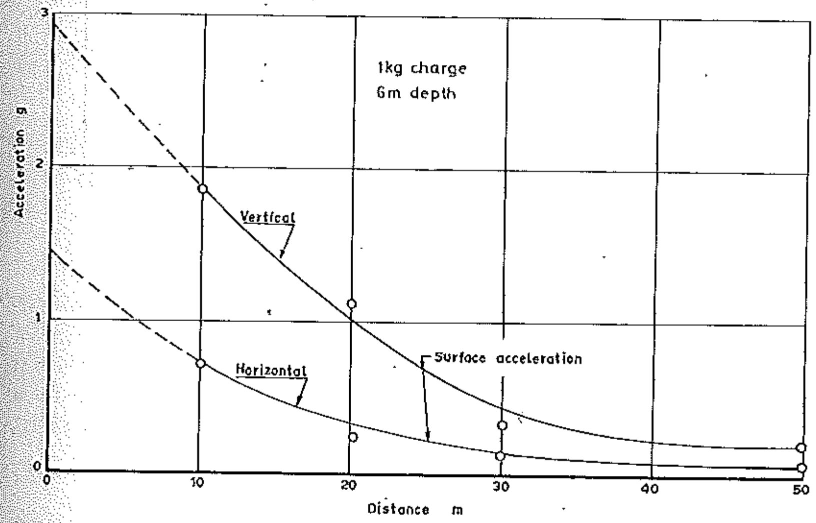

Fig. 5. Horizontal and vertical accelerations as functions of distance from blast point.

It has been shown (PRAKASH and GUPTA, 1967) that in vertical vibrations there is an optimum acceleration to attain maximum compaction and that vertical vibrations are less effective than horizontal vibration in causing compaction of sand. At accelerations higher than the optimum, loosening of the sand takes place. On the assumption that vertical acceleration α_v is about half as effective as horizontal acceleration α_h, the effective horizontal acceleration α_e may be taken as

$$\alpha_e = \alpha_h + 0.5\,\alpha_v = 2.875\ g.$$

Thus, one cycle of 2.875 *g* causes a settlement of 2.4%.

Figure 6 is a plot of acceleration against percentage settlement of a sample of the dam site sand on a horizontal vibration table in the laboratory

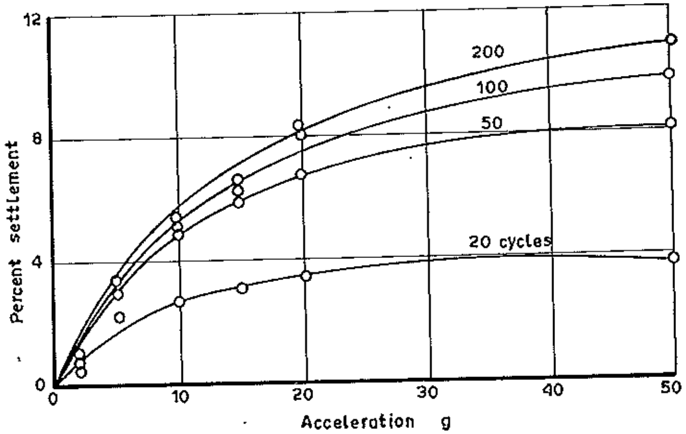

Fig. 6. Settlements caused by horizontal accelerations.

(PRAKASH and GUPTA, 1968). From this figure can be read the combinations of horizontal acceleration and number of cycles for a settlement of 2.4%; these are shown in Table 2. These data are plotted in Fig. 7, which is a plot on a logarithmic scale of number of cycles against acceleration for a 2.4% settlement. The laboratory and field points lie on a smooth curve, which shows that the two sets of data support each other.

Table 2. Combinations of acceleration and no. of cycles for a settlement of 2.4%

α_h or α_e (g)	No. of cycles
0.03	200
0.034	100
0.04	50
0.08	20

In an actual earthquake, the shocks experienced may be of intensities both lower and higher than the design acceleration. If future shock conditions are assumed similar to those for Obra Dam (KRISHNA and PRAKASH, 1967), the details of the shocks to which the dam will be subjected in its lifetime are likely to be as shown in Table 3. The shocks have been converted to the equivalent number of cycles at a horizontal acceleration of 0.1 g by means of the curve in Fig. 7. It can be seen that the dam is likely to undergo

the equivalent of about 250 cycles of an effective horizontal acceleration of 0.1 g.

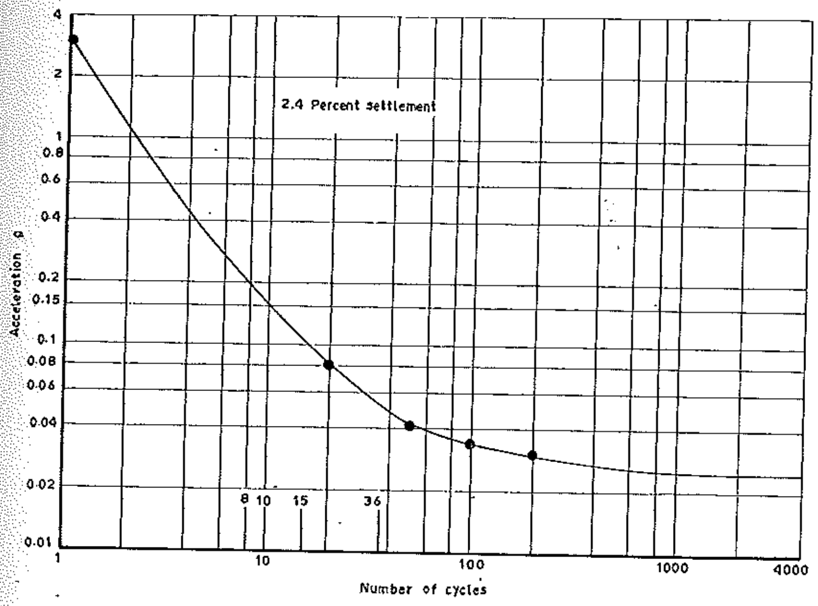

Fig. 7. Relationship between acceleration and number of cycles to produce a settlement of 2.4 per cent.

Table 3. Possible lifetime shock details for Tenughat dam

No. of Earthquakes	Maximum α_e (g)	No. of Cycles	Eguivalent no. of cycles at 0.1g (from Fig. 7)
1	0.2	5	9
	0.15	10	15
	0.10	20	20
	0.05	50	21
2	0.15	10	30
	0.10	20	40
	0.05	30	25
3	0.10	10	30
	0.05	20	25
10	0.05	10	42
Total			257

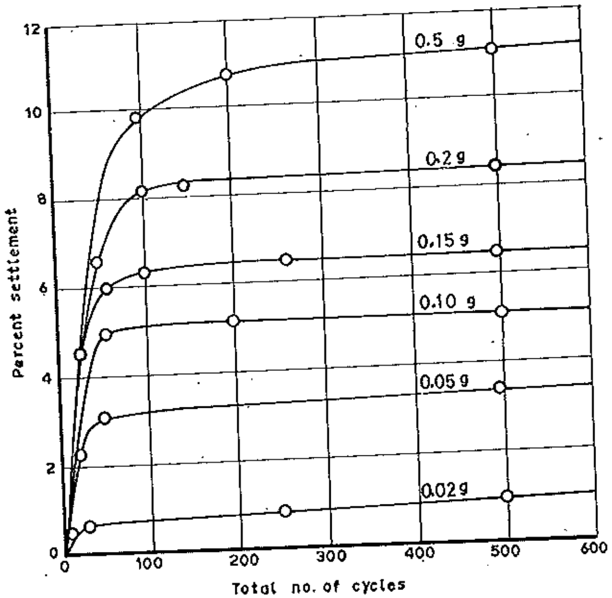

Fig. 8. Relationship between settlement and number of cycles for the sand under horizontal vibration in the laboratory.

Figure 8 is a plot of number of cycles against per cent settlement obtained from laboratory tests on a sample of the sand deposit using a horizontal, steady state vibration table; from this, the settlement of the deposit with an initial relative density of about 20% for 250 cylces of 0.1 *g* is seen to be about 5%. For the 15 m thick sand deposit at the dam site this would mean a settlement, therefore, of 75 cm. The relative density of the sand deposit increases with depth, however, and it may be assumed that this varies with depth at the Tenughat dam site in the manner reported by YOKOVLEV (1967), i.e. the relative density from the surface to a depth of 3 m is 30%, below that it is 40% for the remaining 12 m. The total settlement of this deposit with variable relative density can be assessed from Fig. 9 as follows (PRAKASH and GUPTA, 1968):

a) The maximum settlement of the sand with a 30% initial relative density is about four-fifths the maximum settlement of that with a 20% initial relative density, at an acceleration of 0.1 *g*.

b) The maximum settlement of the sand with a 40% initial relative density is about two-fifths the maximum settlement of that with a 20% initial relative density, at an acceleration of 0.1 *g*.

It has been shown that the total settlement of the sand deposit with a 20% initial relative density when subjected to 250 cycles of an acceleration of 0.1 *g*. is 5%. Under the same conditions, therefore, a 30% initial relative density will give a 4% settlement, and a 40% initial relative density will give a 2% settlement. The total settlement of the sand deposit at the Tenughat dam site is, therefore, likely to be 0.04×3 m plus 0.02×12 m, or 36 cm.

The estimated settlement for the dam of about 0.4 m is not excessive. The slopes of the dam section, however, will need to be protected by additional rip rap and a flexible apron; extra free board may also be provided.

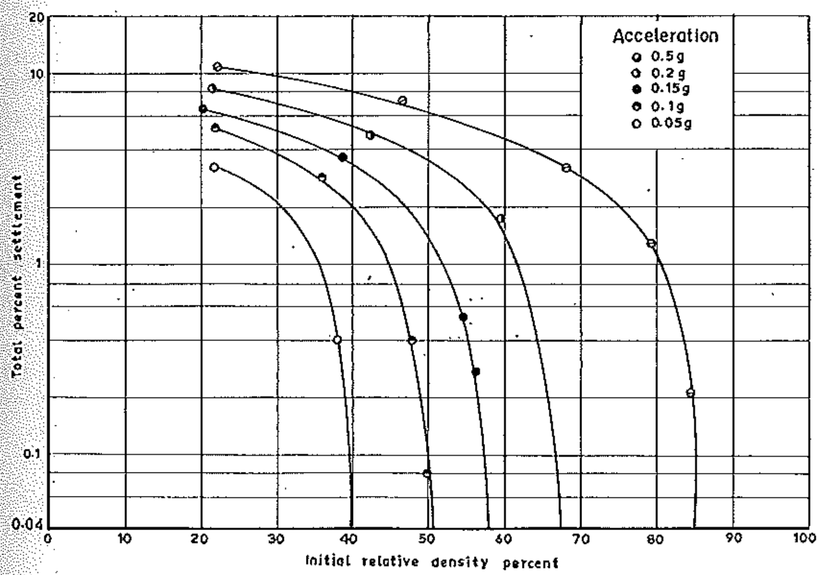

Fig. 9. Settlement as a function of initial relative density of sand.

CONCLUSIONS

The following conclusions are arrived at on the basis of the field blasting tests and their correlation with the laboratory data. Similar behaviour is likely to be exhibited by other similar sands.

1. Tenughat dam sand is not likely to liquefy under the anticipated ground motion and, therefore, compaction of this sand prior to the dam construction is not necessary.
2. The field data obtained on settlements under vibration are in conformity with the laboratory data obtained previously.

ACKNOWLEDGEMENTS

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