International Conference on Case Histories in Geotechnical Engineering

(1988) - Second International Conference on Case Histories in Geotechnical Engineering

02 Jun 1988, 10:30 am - 3:00 pm

# Deformation Response of Some Earth and Rock-fill Dams

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Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 3.52

# Deformation Response of Some Earth and Rock-fill Dams

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SYNOPSIS: Vertical compressional data obtained from 10 earth and earth rock fill dams built in India has been analysed for during construction and post-construction response. The performance of these dams has been compared with some dams built in USA wherein the construction practices have been similar. The contributions of various factors, namely height of embankment, gradation and plasticity of soil, and placement conditions of moisture and density have been examined. A major portion of the total compression occured by the end of construction. These compressions were found to be the functions of the height of the embankment. Both the compressions across and along the valley have been found to be small.

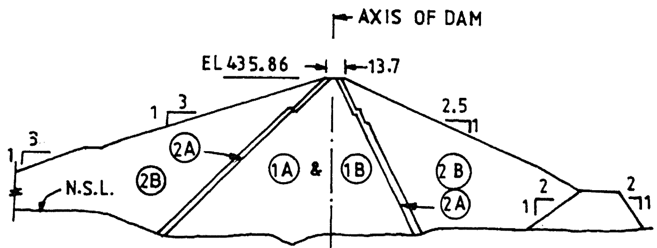
## INTRODUCTION

A large number of earth and earth rockfill dams have been constructed in India during the last four decades. It is believed that there are as many as 1600 large dams constructed in India. The highest earth structure constructed so far has been about 130 m height and the one with a height of 240 m is under construction and more such high earth structures are in the planning stage. The embankment dams which have already been constructed were designed safe against failure by rupture and were expected to undergo compressions of safe value without excessively distorting the structure and its function.. To check the performance of these dams, they were instrumented to measure compressions within the body of the dam and the foundation and also to measure and control the development of pore water pressures. The practices generally adopted by USBR have been followed in choosing and selecting soils for different zones of earth embankment dams, in laboratory and field testing, in controlling placement conditions of density and moisture content, in laying the thickness of layers for fine grained, coarse grained and rockfills and also in the technique of compacting the soils. The cross-arm devices installed were similar to those adopted by USBR. The construction periods were longer for the Indian dams. The performance ot these dams was in no way different from those of USBR as far as the extent and nature of compressions are concerned.

This paper presents the case histories of 10 Indian dams built in different geological formations. Their performance in terms of embankment compression has been analysed and compared with a few dams of USA. These fifteen dams have indicated definite trends of vertical compression during construction and after construction with the height of the embankment. The influences of soil parameters like Atterberg limits, grain size distribution and placement conditions have also been examined.

## BEAS DAM

Beas dam is situated in the Himalayan foot hills 19.3 Km. south of Kangra. It is a central earth core-gravel shell type dam with a maximum height of 132.5m. above the deepest foundation level, as shown in Fig.1.




(1A) Selected clay stone; (1B) Selected sand rock; (2A) Selected sand and gravel; (2B) Selected sand gravel Cobbles and Boulders

Fig.1 Cross-section of Beas Dam

### Geology

The Dam site is characterised by the presence of sedimentary rocks of alternative layers of sand rock and clay shale of the Upper Shivalik formation. A bed of boulders was located from 27 to 76 m. below the ground level. The clay shale is generally massive but includes silt and sand fractions. The sand rocks are coarse grained and showed considerable loss of strength upon soaking.

### Construction Material

The impervious core was made up of the clay stone and sand rocks. The material containing more than 50 per cent of clay shale was placed in zone 1(a) whereas the material containing more than 50 per cent sand rock in zone 1(b). The material of the zone 1(a) contains 70 per-cent finer than 200 mesh and zone 1(b) contains 40 per cent. For the filter and the previous zone, hard quartzite with 22 to 31 per cent sand and 40 to 77 per cent gravel was used.

## Design Properties

The properties of the soil for core adopted in the design of dam were as follows:

| | | |
|---|---|---|
| Bulk density | : | 2.08 g/c.c. |
| Saturated density | : | 2.16 g/c.c. |
| Specific gravity | : | 2.67 |
| Permeability | : | $10^{-6}$ cm/sec. |
| Angle of shearing resistance | : | $26.5^{\circ}$ |
| Cohesion | : | 0.35 kg/sq. cm. |

## Fill Placement and Compaction

The fill placement for impervious zone was carried out in 20 cm. thick layers compacted to 15 cm. The specification allowed a minimum Proctor's density of 98 per cent and maximum 104 per cent. The laboratory Proctor's density was 1.96 g/c.c. The compaction moisture content specified varied from +1 per cent to -2 per cent of the optimum moisture content (i.e. 18 per cent).

## Instrumentation

For the measurement of settlement of foundation and compression in the dam, seven USBR telescopic cross-arms were installed in the body of the dam. Three each at station 74 and 60 (at right abutment and central portion) and one at station 47 (on left abutment) were installed and labelled as A to G. To measure the cross valley deformation, six of the telescopic cross-arms were provided with internal horizontal movement devices at 30.5 m. vertical intervals. An Inclinometer was installed at the deepest section through the impervious core. Surface movements to measure both settlement and horizontal alignment were set up on the upstream and downstream faces (Berry 1975, Char 1979).

## Observations

The settlement of individual cross-arms against their elevation have been plotted as shown in Fig. 2. From the figure it is clear that the maximum settlement occurred at mid height of the dam.

Settlement of the individual cross-arm for each of the settlement devices has been plotted. It is observed that the maximum settlement have occurred in the device F which was embedded in the impervious core. During the early construction period compression was faster which slowed down with time. On an average 22.5 per cent of the total compression took place during the first one month after placement. Generally lower layers showed higher compression than the upper layers.

The total settlement has also been plotted as the percentage of the height of the embankment fill height for the period of the raising of the embankment as shown in Fig.3. From this plot, it is seen that the settlement curve largely follow the pattern of the fill placement curve with respect to time, (Ramamurthy 1984).

It is further observed that the maximum settlement took place in the settlement devices embedded in the impervious core. The highest percentage of settlement, 2.02 per cent, had taken place at the device C which was embedded in the core and where the height of fill was maximum.

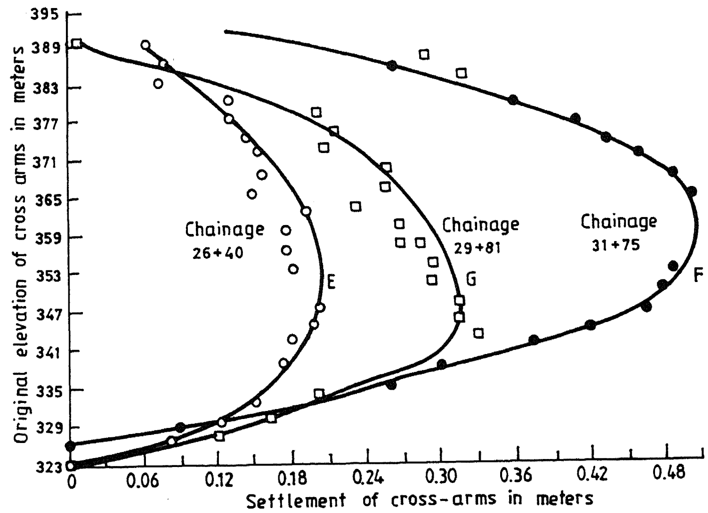



Fig.2. Settlements of Cross-arms in Beas Dam

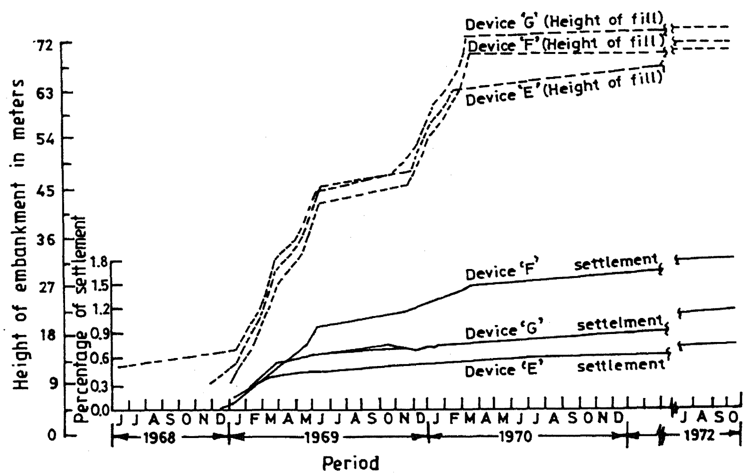



Fig.3. Settlement with Height of Fill in Beas Dam

RAMGANGA DAM

The main earth and rockfill dam (127.5m high) constructed across Ramganga river at 3.2 Kms. upstream of Kalagarh in district Garhwal Fig.4.

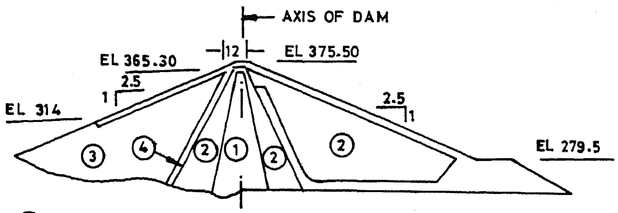



Fig.4. Cross-section of Ramganga Dam

The dam was located in the gorge portion between two right angled bends and the diversion tunnels and surplusing works located on the right flank together with the Power Houses.

Geology

The dam rests on alternate bands of sand rocks and clay shale of middle Shivalik age. The general dip of the rock is towards upstream. The sand rock is massive, coarse jointed and poorly consolidated, whereas the clay shale layers vary from soft clays to silt stones. In the river bed the rock formations are covered by river bed deposits consisting mainly of sand, gravel and boulders. Percentage of fines being quite low.

Construction Materials

The inner core consists of crushed clay shale and is encased on either side by crushed sand rock. Both these materials are impervious in nature. The permeability of the crushed clay shale and the crused sand rock is of the order of $0.8 \times 10^{-8}$ cm/sec. and 0.1 to $2.6 \times 10^{-6}$ cm/sec. respectively.

The main source of pervious material for the shell of the dam is river bed deposit; on an average 50 per cent of the material is above 7.5 cm. in size, 17 per cent is sand and about 3 per cent is silt and clay.

Design Properties

The properties of the soils adopted for the design of the dam were as follows:

| Properties | Impervious Material<br>Sand rock/ Clay shale | Pervious Material |
|---|---|---|
| Bulk density g/c.c. | 2.0/2.08 | 2.16 |
| Saturated density, g/c.c. | 2.2/2.24 | 2.24 |
| Specific gravity | 2.67 | 2.67 |
| Angle of shearing resistance | $22^{\circ}$ | $36.5^{\circ}$ |

Fill Placement and Compaction

The clay stone was compacted by 12 to 14 passes on 15 cm. thick layers, for sandstone the number of passes varied from 17 to 21 on layers of 30 cm. thick. The river bed material was compacted by 2-3 passes of 10 tonne vibratory roller on 60 cm. thick layer. The specification allowed 90 per cent of proctor density. The laboratory proctor density was 1.76 g/c.c. The compaction moisture content was specified as -2 per cent of the optimum moisture content.

Instrumentation

Six numbers of USBR cross-arm devices coupled with horizontal movement plates were installed at various sections and zones of the dam, to record settlements and horizontal movement in the body of the dam.

Observations

The settlement of the individual cross-arm in each of the six devices were plotted against their original elevation. It is observed that the maximum settlement took place approximately at the mid-height of the embankment.

The settlement of individual cross-arm for the devices have been plotted in the form of contours of vertical settlement. It is observed from these contours that maximum settlement occurred at about the mid-height of the embankment.

The total settlements have been plotted as percentage of the height of the embankment for the period of raising of the embankment. It is observed that maximum settlements had taken place in the devices embedded in the impervious core and where fill heights are maximum (Verma and Raj 1978).

The total compression in the fill was about 1.8 per cent of the height of the dam. In the clay stone forming the core, the percentage compression at 10 Kg/sq. cm. was about 3.3 per cent and in the sandstone this value was 2.9 per cent.

TAWA PROJECT

Tawa dam project is located across the river Tawa, a tributory of river Narmada in the district of Hoshangabad of Madhya Pradesh. The reservoir is created by constructing a 36.6 m. high earth dam with a masonry spillway in the river bed. Two saddles which exist on the left flank are also connected by the earth dam. The total length of the embankment is about 1.64 Km.

Geology

The rocks met with at the dam site are Pachmarhi sandstones which are gritty in nature. Similar formation termed as the Bijori formation also exists, but with interbedded carbonaceous shales and coal seems with occasional layers of red clay stones. Both the formations have upstream dips.

Construction Materials

The inner core consists of clay and is encased on either side by semi-impervious material. The permeability of the core material and the casing material is of the order $12.2 \times 10^{-6}$ cm/sec. and $42 \times 10^{-6}$ cm/sec. respectively. The properties adopted in the design are given below:

| Properties | Impervious | Semi-pervious | Foundation |
|---|---|---|---|
| Bulk density, g/c.c | 2.0 | 2.17 | 2.06 |
| Saturated density, g/c.c | 2.04 | 2.20 | 2.10 |
| Angle of shearing resistance | $19^o$ | $30^o$ | $25^o$ |
| Cohesion, kg/sq.cm | 0.155 | 0.105 | 0.105 |

Instrumentation

To measure compression within the embankment six USBR cross-arm devices coupled with horizontal movement plates were installed at three sections viz. 16.60, 36.35 and 44.10 as shown in Fig. 5.

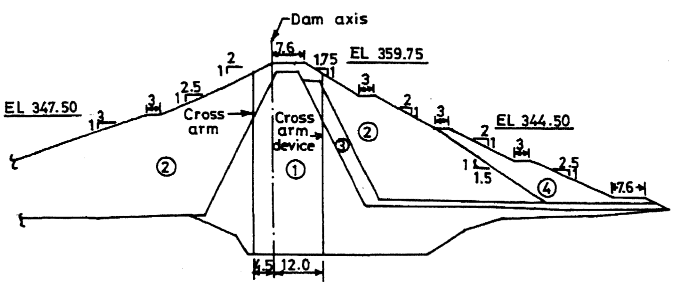



Fig.5. Cross-section of Tawa Dam

Observations

The settlement of the individual cross-arm of all the settlement devices were plotted against their original elevation.

The settlement of individual cross-arm for the devices have been plotted in the form of contours of vertical settlement. It was observed that the maximum settlement occurred at about the mid height of dam. The embankment settlements were larger than those observed for other dams, (Ramamurthy, 1984).

BUGGAVAGU DAM

A 31 meters high Buggavagu dam constructed across Buggavagu stream is situated on Nagarjuna Sagar Right Canal in Andhra Pradesh. The canal passes through Buggavagu streams in between 27.2 Km. and 33.0 Km. It is a rolled earth dam consisting of an impervious core zone with semi-pervious shell and upstream and downstream rock toes.

Geology

The foundation of the dam consists of Nepa and quartzite variety of rocks with a few widely spaced earth joints except in a length of 279 m. where it is soft conglomerate.

Construction Materials

The average properties of soils for both core and shell zones of the dam are given below:

| Characteristics | Core zone | Shell zone |
|---|---|---|
| Liquid Limit | 58% | 31% |
| Plasticity Index | 37% | 23% |
| Maximum Dry Density | 1.60 | 1.84 |
| Average Embankment Dry Density, g/c.c. | 1.66 | 1.92 |
| Optimum Water Content | 18% | 10% |
| Average Construction Water Content | 17% | 9% |

Instrumentation

The dam is provided with two sets of cross-arm (USBR) at 1.5 m. vertical interval for measuring settlement within the embankment. Settlement observations of various cross-arm showed that the maximum vertical movement of any individual cross-arm during construction period occurred near the mid height of the dam and equals to 34 cm.

The end of construction settlement at upstream installation of Buggavagu dam has been observed to be 1.49 per cent of the embankment height.

BOR DAM

Bor dam is a rolled earthfill structure, 35.7 m. high above lowest river bed level across the Bor river, a tributory of Nardha river in Wardha district of Maharashtra.

Geology

The dam lies in an area covered by rocks of the Deccan trap formation comprising of massive basalt.

Construction Materials

The dam embankment comprises of a core zone of yellowish silty clay, mostly ML type with shell of murmy soils reddish grey in colour (SC type).

Properties

Properties of the soils used for the core shell are as follows:

| Characteristics | core zone | shell zone |
|---|---|---|
| Liquid Limit | 38 to 52% | 30 to 38% |
| Plastic Limit | 10 to 17% | Non-plastic |
| Dry Density | 1.6 g/c.c. | 1.87 g/c.c. |
| Optimum Moisture Content | 18 to 22% | 11 to 19% |
| Permeability cm/yr. | 7.3 - 7.6 | 51.8 - 167.7 |
| Specific Gravity | 2.67- 2.71 | 2.74 - 2.91 |

Instrumentation

The dam is provided with a USBR cross-arm installation in the core zone having 22 cross-arms at 1.5 m. interval.

Results

At the end of construction, the settlement has been on the lower side i.e. 0.8 per cent of the embankment height only. Post construction settlement during the following 2 years has been much higher i.e. 1.1 of embankment height. It has been observed that the maximum portion of settlement was recorded by the lower level cross-arm.

Settlement of embankment during construction though on lower side was still within the range of settlement observed on USBR dams of same soil classification i.e. ML soil (Gould, 1953,1954).

Lower placement moisture as compared to optimum moisture content seems to be mainly responsible for the lower settlement during construction. Substantial consolidation of soil due to rearrangement of soil gains after saturation of embankment seems to be mainly responsible for higher post construction settlements. It may be noted that although soil was compacted to 97.0 per cent of modified proctor maximum dry density but the value of average placement density was still substantially lower at 1.63 g/c.c. as against natural dry density of the soil which was found to be 1.68 to 1.71 g./c.c.

SETTLEMENT CORRELATIONS

Settlement of embankments of the end of construction versus height of embankment at cross-arm installations in respect of 15 earth and rockfill dams (5 of USA, Gould 1953, 1954) and 10 of Indians) has been plotted on log-log scale as shown in Fig.6. It is seen from this figure that at the end of construction, the compression is a power function of H, (i.e. the height of embankment). This data is included in Table 1. The best fit through the plot is given very closely by the relationship (Jain, 1985).

$$s_c = 0.007\ H^{1.22} \qquad (1)$$

where,

$s_c$ = settlement in metres

H = embankment height in meters

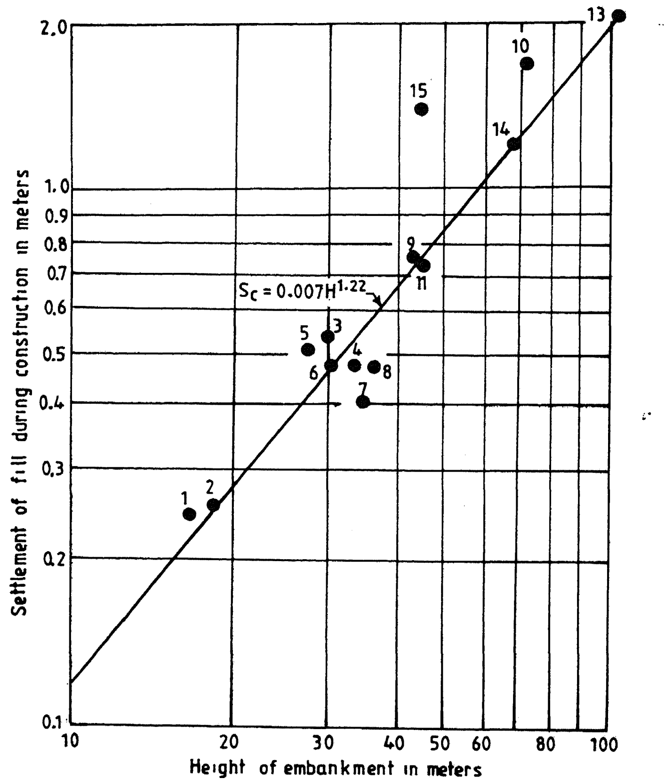



Fig.6. Settlement Variation during Construction with Fill Heights

Post-construction compression of the fill in respect of the dams has been plotted against height of the embankments on log-log scale. The points so obtained are very scattered and the plot does not indicate any definite correlation. It shows that the height of embankment of a rolled earth dam seem to have influence on the post construction settlements.

Figure 7 gives a plot between the height of embankment and the total compression on log-log scale. It indicates a best fit relationship to the data given by

$$s_t = 0.014\ H^{1.1} \qquad (2)$$

where,

$s_t$ = total settlement;end of construction and post-construction, m,

H = embankment height in meters.

Most of the dams referred above have indicated increasing post-construction compression with the the increasing variation in the compaction moisture content allowed on the dry side of optimum moisture content. These dams have been compacted at moistures ranging from 0.2 to 4.0 per cent below optimum moisture content except for two dams which were compacted at 1.0 and 2.0 per cent above the optimum moisture content.

TABLE 1. Settlement Observational Data of some Embankment Dams

| Sl. No. | Name of Dam | Soil in Core | Degree of compaction % | Max.height of cross-arm installation in meters | Settlement during construction in meters | Post-construction settlement in meters | Total Settlement in meters |
|---|---|---|---|---|---|---|---|
| 1. | Nanak Sagar, India | CL | 99.0 | 16.36 | 0.247 | 0.148 in 5 1/2 yrs. | 0.395 |
| 2. | Baur, India | CL | 99.0 | 18.59 | 0.262 | 0.061 in 3 yrs | 0.323 |
| 3. | Moosa Khand, India | CL | 101.2 | 30.48 | 0.533 | 0.092 in 3 1/2 yrs. | 0.625 |
| 4. | Meja, India | CL | 104.0 | 34.30 | 0.469 | 0.131 in 3 1/2 yrs. | 0.600 |
| 5. | Jigro, India | CL | 101.5 | 27.59 | 0.524 | 0.11 in 3 yrs. | 0.634 |
| 6. | Bhuggavagu, India | CL | 99.0 | 31.1 | 0.463 | 0.143 in 2 1/2 yrs. | 0.607 |
| 7. | Box, India, | CL | 97.0 | 36.3 | 0.289 | 0.400 in 2 1/2 yrs. | 0.689 |
| 8. | Hor-setooth, USA | CL | 98.8 | 36.89 | 0.457 | 0.198 in 3 1/2 yrs. | 0.655 |
| 9. | Jackson Gulach, USA | CL | 100.2 | 44.20 | 0.762 | 0.244 in 3 1/2 yrs. | 1.006 |
| 10. | Granby, USA | SC | 98.8 | 72.56 | 1.73 | 0.05 in 3 yrs | 1.78 |
| 11. | Deer Creek, USA | CL-GC | 99.4 | 46.03 | 0.753 | 0.127 in 8 yrs | 0.88 |
| 12. | Fresno, USA | ML-CL | 99.8 | 23.47 | 0.286 | 0.073 in 14 yrs | 0.359 |
| 13. | Beas, India | CL | 98-104 | 110 | 2.32 | 0.39 in 3 yrs. | 2.71 |
| 14. | Ramganga, India | CL | 99.0 | 67.0 | 1.24 | 0.106 in 3 yrs | 1.346 |
| 15. | Tawa, India | CL | 101.0 | 44.0 | 1.458 | 0.022 in 3 yrs. | 1.480 |

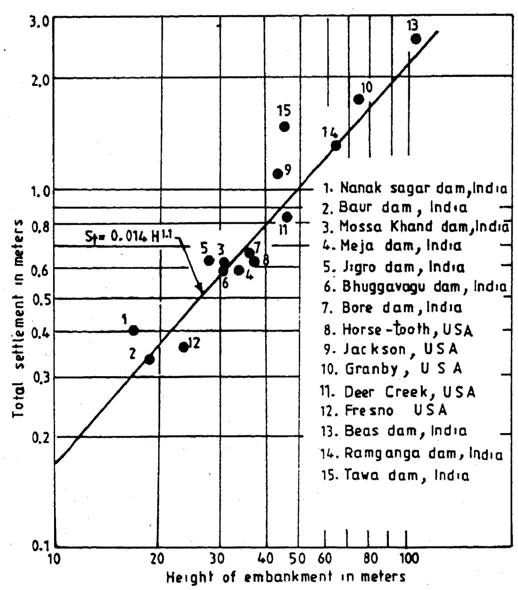



Fig.7. Variation of Total Settlement with Fill Height

Gould (1954) had established that under pressures greater than 7 kg/sq.cm, the compressibility of the embankment is mainly governed by the gradation of soil and plasticity of fines; the latter property has the predominant influence. For the cases of dams presented in this paper no influence of these factors was observed.

Post-construction compression of these dams increased near linearly with the increase of liquid limit which indirectly reflects on the magnitude of the higher compression index of the soils for having compacted on the drier side of the optimum moisture content.

When the data of the degree of compaction achieved has been compared with the total compression, a trend exists indicating lower compression with higher degree of compaction.

## CONCLUSIONS

Based on the data collected from ten Indian earth and earth rockfill dams and some similar embankment dams of USA, the following broad conclusions are made on their compressional response:

1. A major portion of the total compression in earth and earth rockfill dams occurred by the end of construction.
2. Significantly large compression took place in the vertical direction in the central region of the core.
3. Compaction techniques and placement conditions similar to those adopted by USBR; the end of compression and total compression in these dams were found to be functions of the embankment height.
4. Both the compressions across and along a the valley have been small.
5. Larger compression was observed with larger deviations on dry side of the optimum moisture content.
6. No definite influence of mean particle size and plastic limit of soil was observed on the compression of the embankments. On the contrary, a definite influence of liquid limit on the compression was observed. Higher the liquid limit higher was the compression.
7. The degree of compaction achieved during the construction as related to Proctor's maximum dry density did effect the compressibility of the embankment; higher degree of compaction indicated reduced compression.
8. Although the bottom layers of embankments understandably undergo maximum vertical strain, the maximum vertical movement of any individual cross-arm occurred nearly at the mid-height of the embankment.

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