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DESIGN OF BATTERY STANDS OF A POWER PLANT FOR STABILITY AGAINST EARTHQUAKE FORCES

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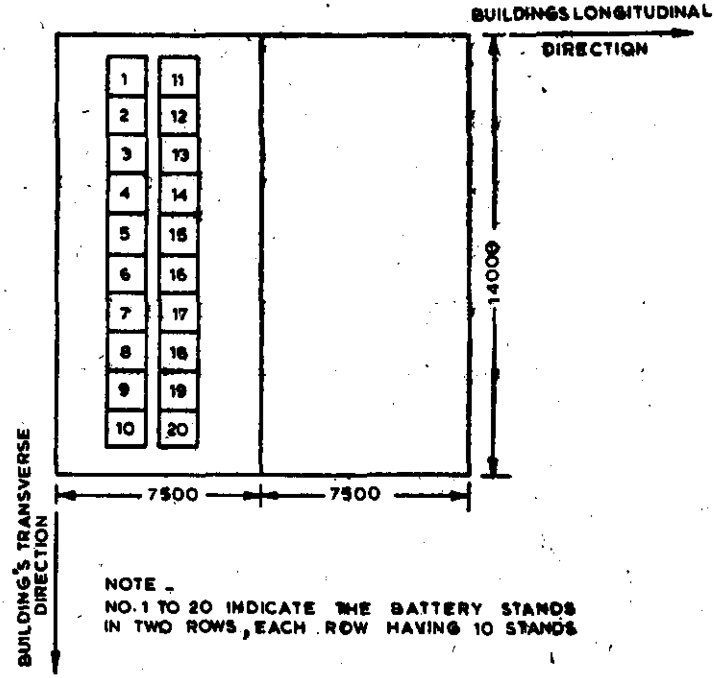
INTRODUCTION

Design of heavy duty batteries and stands system used in an atomic power plant has been carried out for stability against earthquake forces. The batteries are placed on two-tier timber stands each having twelve batteries. The stands are made of timber framing and are arranged in two rows each having 10 frames as shown in fig. 1. There is no connection between the successive elements in order to facilitate their handling, so that they are restrained only by friction against the horizontal earthquake forces. The stands also simply rest on the floor. Since the whole system depends only on the frictional restraints for stability against the horizontal forces, it is found that there are undesirable sliding and overturning instabilities in the system.



NOTE -
NO. 1 TO 20 INDICATE THE BATTERY STANDS IN TWO ROWS, EACH ROW HAVING 10 STANDS

Fig. 1. Sketch Plan of the Bays in the T. G. Building Housing the Battery Stands

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RESPONSE OF THE BUILDING TO GROUND MOTION

The El Centro May 18, 1940 SE component, with accelerations reduced to 90% of recorded values, has been used as the ground motion for design. Peak acceleration responses in the longitudinal and transverse directions of the building at the floor where battery stands are placed are obtained as 0.256 g and 0.711 g respectively. The vertical acceleration of the floor has been assumed to be two-third of the horizontal ground acceleration with its peak of 0.209 g coinciding with peak of the horizontal response acceleration.

PRELIMINARY STABILITY ANALYSIS OF BATTERY STANDS

The height of the center of gravity, h, of the loaded stand is obtained as 1100 mm, and its half base width, b, has been kept originally 322.5 mm, so that the ratio b/h=0.29. Thus the coefficient of horizontal acceleration at the threshold of overturning is given by(1)

$$\alpha_0 = \frac{b}{h}(1-\alpha_v) = 0.29\ (1-0.209) = 0.23$$

Since the threshold acceleration value is exceeded, the liftingup of the stands may either proceed to complete overturning or there may be reversal of the motion and consequent impact. Even the second situation, which is relatively less damaging, should be avoided. Therefore the basewidth of the stands is increased from 645 mm to 895 mm, the sufficiency of which has to be established by detailed analysis.

BATTERY STANDS RESPONSE IN THE TRANSVERSE DIRECTION

A line sketch of the battery stands is shown in Fig. 2. The horizontal stiffness for each of the three transverse frames of a stand for unit load applied at the upper tier level is obtained as 490 kg/cm assuming rigid jointed framework. The effective total weight at this level is obtained as 733 kg. The natural time period of vibration of the stand in this direction is obtained as 0.15 second. Taking the damping as 2 percent of the critical viscous damping, the peak acceleration response of the stand (at point D, fig. 2) is obtained as 0.349 g against the maximum floor acceleration response of 0.256 g. The following table shows the calcula-

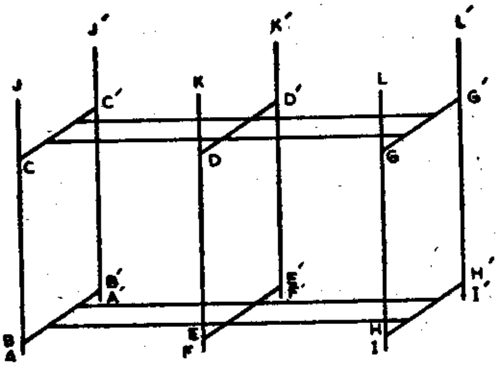


Fig. 2. Line Diagram of the Battery Stand

tion for sliding forces and overturning moments considering the peak vertical acceleration as 0.209 g.

Elevation (m)	Lumped Weight (kg)	Horiz. acc. (g)	Horiz. force (kg)	Vert. force (kg)	Moment due to Horiz. force (kg–m)	Moment due to Vert.* force (kg–m)	Total overturning moment (kg–m)
1.64	660	0.349	230	138	378	61	439
0.55	660	0.256	169	138	93	61	154
1.20	73	0.349	25	16	31	7	38
0.20	63	0.256	16	13	3	7	10
Total	1456	—	440	305	505	136	641

(*Distance from overturning edge=0.895/2=0.4475 m)

Net downward force=1456−305=1151 kg

Threshold force for sliding =0.4×1151=460 kg (μ=0.4)

Maximum horizontal force =440 kg <460; No sliding

Stabilizing moment =1456×0.4475=652 kg–m

Overturning moment =641 kg–m <652; No lifting up.

Hence increase in the basewidth of stands by 250 mm is adequate. It is also seen that overturning is more critical than sliding, the ratio of the moment 641/652 being larger than the ratio of the forces 440/460.

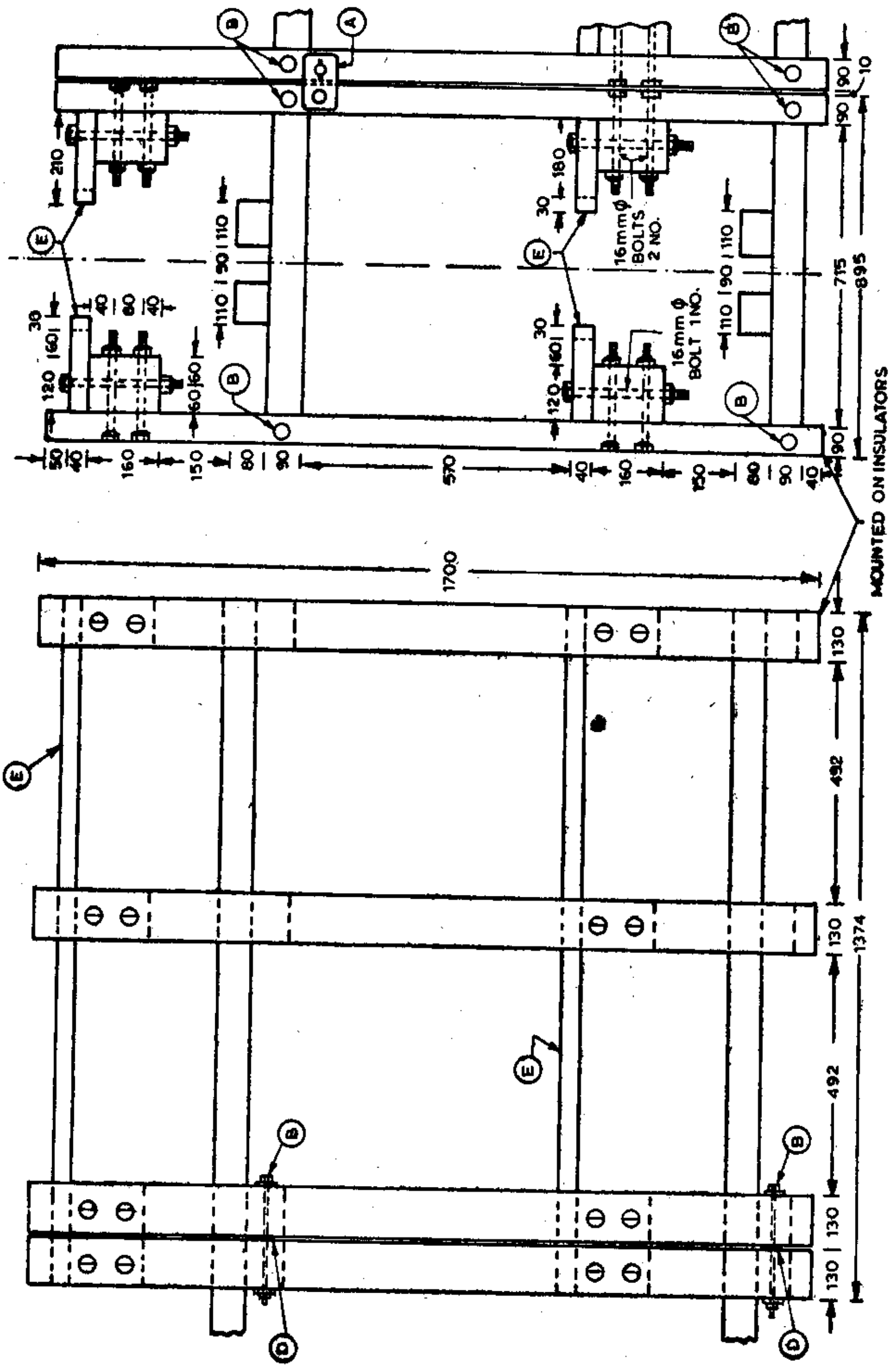
BATTERY STANDS RESPONSE IN LONGITUDINAL DIRECTION

The longitudinal stiffness of a stand is obtained as 1340 kg/cm with the effective weight as 733 kg, the time period of vibration of the stand works out to 0.148 s.

In this direction the peak acceleration response is obtained as 0.822 g against the maximum floor acceleration of 0.711 g.

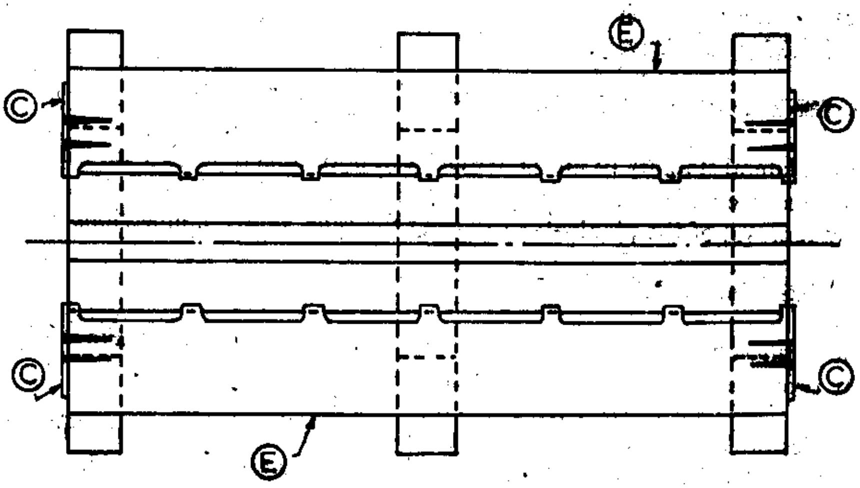
SLIDING OF STANDS

Sliding of the stands occur only in their longitudinal direction, with a maximum of 27 mm for coefficient of friction, μ=0.4. In the transverse direction the accelerations are below the threshold limit of 0.4 g for sliding.



NOTE _
1 _ PLAN AND EXPLANATORY NOTES ARE GIVEN IN FIG. 3b

FIG. 3a _ WOODEN STAND FOR 12- CELLS



NOTES :

1—Stand should be painted with two coats of anti-acid black paint

2—No. of stands per set : 20

3—Metal connecters 'A' allow movement of ±5 mm. Three connectors are provided for a pair of stands so that each transverse frame of stand is connected. (Design axial force : 126 kg per connector)

4—Bolt 'B' 10 mm DIA with M. S. Washers 36 mm DIA×4 mm Th. and Rubber washers 'D' 10 mm thick. Two bolts between stands to connect all ten rigidly in a row

5—Metal strips 'C' to reinforce end projections of plank.

6—All timber joints to have suitable metallic straps to transmit full moments. The connectors 'A' may lie above the straps

7—Exact horizontal cross sectional dimension of plank 'E' and its projection widths will depend upon the dimensions of the battery and may be modified accordingly

8—The drawing is not to scale

Mat. Timber : Teakwood (C. P.)

Fig. 3 b—Plan of Wooden Stand for 12-Cells

SLIDING AND OVERTURNING OF BATTERIES

The minimum coefficient of friction is 0.32 between the tray and battery insulators, where maximum sliding of 45 mm and 53 mm are obtained at the stands lower and upper tier levels respectively in the longitudinal direction of the stand. In the transverse direction the sliding is only 0.2 mm for the upper tier batteries. The resultant sliding would therefore be nearly in the longitudinal direction of stands.

Also the threshold acceleration coefficient for overturning, a/h is obtained as 0.20 and 0.33 in the two directions of a cell. Thus a cell would overturn in the more critical direction having $a/h = 0.20$, since μ $(= 0.32) > 0.20$. Analysis indicates complete overturning of the batteries in both the tiers. In the other direction the peak acceleration response at the upper tier batteries is 0.349 g which marginally exceeds the sliding and overturning threshold limits of 0.32 g and 0.33 g respectively.

ARRANGEMENT FOR SUPPORTING THE CELLS LATERALLY

To provide lateral stability to all the batteries in both directions, a 4 cm thick timber plank has been introduced on each side of the batteries in both tiers as shown in fig. 3. In order to facilitate easy removal of the planks for servicing the cells, bolted connections have been used.

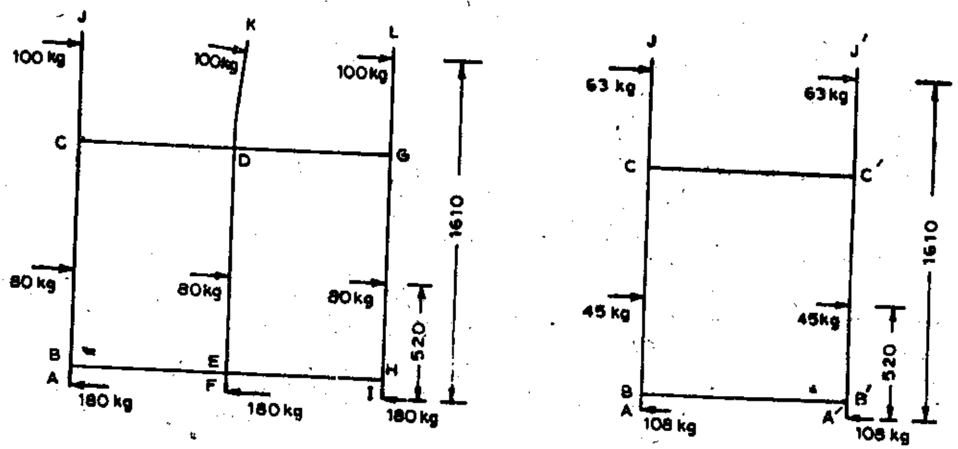
CONCLUSIONS AND RECOMMENDATIONS

1. The lifting-up of the freely resting battery stands under earthquake motion should be prevented by providing a sufficiently large base width.

2. It is desirable to make the battery stands as rigid as possible to minimize building up of the response. That is, the natural time periods of vibration of the stand in the two principal directions should be small compared to the dominant time periods of the floor motion in the corresponding directions. To ensure stiffness of the timber joints, metallic straps capable of transmitting the full joint moments are recommended.

3. To prevent differential sliding motion and hammering between adjacent stands in a row, thus saving the copper connectors from damage, it is suggested that all the stands in a row be interconnected by steel bolts and filler rubber washers at the lower as well as the upper joints.

4. Special transverse connections between stands in adjacent rows can also be provided, as shown in fig. 3 at A, for additional restraint against overturning of the stands beyond a certain degree of lifting.



NOTE :
Seismic forces on the end transverse frames of a stand are half that on its middle transverse frame

a—Seismic forces on one of the two longitudinal frames of a stand

b—Seismic forces on the middle transverse frame of a stand

Fig. 4.

5. It is necessary to hold the batteries in both tiers against overturning and sliding by providing the timber planks supported by the columns of the stands through wooden blocks, as shown in fig. 3. The planks should be designed to hold the batteries 'loose fit'. The bolted connections should also be designed for least possible movement of the planks relative to the stand to avoid overstressing of the intercell copper connectors.

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