CONTROL OF SEISMIC EFFECT ON SWITCHYARD EQUIPMENTS BY VIBRATION ISOLATION SYSTEM

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SUMMARY

The safety of switchyard electrical equipments and their supporting structures during an earthquake is an important aspect to be considered in the design. Very often the supporting structures are short and stiff so that they can greatly amplify the ground motion and transmit high acceleration to the equipment during an earthquake. This paper presents two methods for controlling the transmission of acceleration to the equipment. One is by designing the supporting structure on dynamic considerations thereby introducing in it sufficient strength and flexibility. The second method is by introducing isolation system consisting of helical springs between equipment and supporting structure. This method controls the acceleration in vertical as well as in horizontal direction. Practical examples of design are presented which demonstrate how the safety of equipment, supporting structure and isolation springs can be ensured.

INTRODUCTION

The existing supporting structures for equipments of switchyard are usually short in height and carry light load on the top. Such characteristics lead to short period of structures requiring high seismic coefficient for the design of equipments. The safety of equipments and its supporting system is of vital importance during an earthquake as their failure can cause power failure. This paper describes two methods by which the flexibility of the supporting system could be increased which would give longer time period of vibration and thereby transmit smaller acceleration to the equipment.

The first method is by designing a cantilever type supporting structure on dynamic considerations thereby introducing in it the required flexibility. The supporting structure is then checked for its strength. This design will not isolate accelerations in vertical direction as the cantilever is rigid in that direction.

The second method is by introducing isolation system consisting of helical springs between equipment and supporting structures. The stiffness of helical springs in axial as well as in transverse direction, are so chosen as to control the vertical and horizontal accelerations at equipment level. Practical example of design of isolation system of equipments at a power house is presented to demonstrate how the safety of equipment can be ensured during an earthquake.

GLOSSARY OF TERMS

g - Acceleration due to gravity
h_u- Uncompressed height of spring
K - Total stiffness of isolating system
K_x- Horizontal stiffness of one spring

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K_y – Vertical stiffness of one spring
L – Horizontal force acting at the C.G. of equipment
n – Number of active coils of spring
R – Mean coil radius of spring
S_{ah} – Acceleration acting at equipment level in horizontal direction
S_{av} – Acceleration acting at equipment level in vertical direction
T – Natural period of system
V – Maximum vertical force in one spring
W_e – Weight of equipment
τ_1 – Maximum shear stress in spring with earthquake load
τ_2 – Maximum shear stress in spring without earthquake load
δ_{st} – Static deflection of spring in vertical direction
Δ_{st} – Deflection of cantilever type of supporting structure at equipment level under static load

DESIGN EARTHQUAKE AND ACCELERATION SPECTRUM

The basic parameters for determining the seismic effect on equipment and supporting structure is the Design Earthquake Accelerogram. The Design Earthquake can be established from a detailed study of the seismicity of the site. Such a study should reveal expected earthquake in the region and the ground motion at the site in the form of accelerogram, that is, an acceleration vs. time record. In this study the use of a modified accelerogram derived from longitudinal component of Koyna earthquake of December 11, 1967 was made. The modified accelerogram was obtained by multiplying the time base of original accelerogram, by 1.5 (Jai Krishna et al.). The damping factor is assumed to be 5% of critical. The acceleration spectrum for the Design Earthquake using 5% of critical damping is shown in Fig. 1 for the site. This spectra has been used for horizontal motion. For the vertical direction the spectra is obtained from horizontal spectra reducing it by 50% in accelerations amplitude only.

It is clear from the spectra that when the time period of the system lies in the range of 0.68 sec to 0.84 sec the acceleration remains less than 0.5 g. Also when the period of the system is more than one second the acceleration remains within limits.

Similarly for vertical direction spectra it is clear that when the time period of system in vertical direction lies between 0.68 to 0.84 second or when the time period of system is more than 1 second, the acceleration remains less than 0.25 g.

DESIGN CRITERIA FOR EQUIPMENTS

The power house equipments are usually required to be designed for an acceleration of 0.5 g in horizontal direction and 0.25 g in vertical direction. The suppliers and manufacturers have to take care of this safety requirement. Assuming that the equipments are strong enough in this manner, it has to be ensured that they are not subjected to higher accelerations when in service.

For the Design Earthquake Spectrum given in Figure 1 the natural period of vibration of the system should be close to one second in horizontal as well as in vertical direction to control equipment acceleration.

CANTILEVER TYPE DESIGN OF SUPPORTING STRUCTURE[7]

The supporting structure of switchyard equipment should be strong enough to carry the static loads and dynamic loads. It should be flexible enough to generate an acceleration not exceeding 0.5 g in horizontal direction at equipment level. It is seen that configuration shown in Figure 2a provides a good solution. This type of vertical cantilever structure has enough flexibility in horizontal direction. The structure can be idealised as a single degree freedom system as shown in figure 2b for calculating the time period of the structure as follows.

$$T = 2\pi\sqrt{\frac{\Delta st}{g}}$$

By keeping the time period between the range 0.68-0.84 seconds the structures are designed to carry the vertical loads and inertia forces, (Arya et al., 1978). The structure is rigid in vertical direction so the maximum ground acceleration will be transferred as it is to the equipment level. So if the maximum ground acceleration invertical direction is less than 0.25 g the design is alright but if it is greater than 0.25 g the problem of transmission of vertical acceleration will be there.

The second method gives a solution for this problem.

DESIGN OF ISOLATION SYSTEM FOR EQUIPMENT

This method controls horizontal as well as vertical acceleration of equipment due to an earthquake.

The method is based on design of helical springs which act as isolator in horizontal as well as in vertical direction. These springs are mounted on top of conventional type of supporting structure details of which are shown in Fig. 3. Such structures are very rigid and hence for analytical purpose, springs are assumed to be resting on ground.

Weight of equipments for which isolators are designed lie between 450-1100 kg. To obtain a natural period of one second for above weights very soft springs are required which cause excessive displacements due to earthquake forces. To take care of above problem, additional weights of 1 ton or 1.5 ton are kept between springs and equipment. These weights permit the use of stiffer springs and hence cause less displacement due to earthquake forces.

To avoid the moment, caused by horizontal inertia forces (We x a), to act on spring, spherical hinges are provided between spring and equipment. The presence of these hinges permit the moment to be transferred in form of vertical upward and downward force on springs. The magnitude of these forces will depend upon the centre to centre distance of two springs.

A schematic diagram of the complete isolating system is as shown in Fig. 4.

Stiffness of Spring[2]

According to the design spectra for the site under consideration, the acceleration of equipment in horizontal and vertical direction will remain within permissible limits i.e. 0.5 g in horizontal and 0.25 g in vertical, if the time period of the system is 1 second or more. The required stiffness of spring in horizontal and vertical direction is calculated by following formula.

$$K = \frac{4\pi^2 (We + Wa)}{g\, T^2} \qquad \ldots (1)$$

In this case the value of T is one second.

Since four numbers of springs are used, the stiffness of each spring in horizontal as well as in vertical direction will be

$$Kx = Ky = K/4 = \frac{\pi^2 (We + Wa)}{g} \qquad \ldots (2)$$

Selection of Spring Specifications (2)

The working height of spring (hs) is assumed to be 60 cm. The hs/D is found from Fig. 5, corresponding to known value of Kx/Ky (one in this case) and st/hs (0.41 in this case). The value of mean coil diameter (D) is hence obtained which is 50 cm in this case.

The diameter of wire is then calculated by well known formula

$$Ky = \frac{G\, d^4}{8n\, D^3} \qquad \ldots (3)$$

Number of active coils (n) is assumed to be 6.

The design details of isolation system as obtained for five different equipments are given in Table 1.

Stability of Springs (2)

The springs should remain stable under normal as well as in earthquake condition. When a system is in the condition of minimum potential energy the stable equilibrium exists. During horizontal deflection of the spring, the vertical stiffness of spring decreases as a result of eccentric load. The mounted equipment is therefore lowered, and its potential energy is reduced. If stability is to be maintained, the loss of potential energy must be atleast balanced by an increase in strain energy in the spring. Increased strain energy in the spring results from (i) its horizontal deflection (ii) its increased vertical deflection. From this energy relation it is found that the system is stable when,

$$\frac{Kx}{Ky} \geqslant 1.2 \left(\frac{st}{hs}\right)$$

Check for Strength and Deflection of Springs (1)

Springs are then checked for following :

a) Total compression in any of springs is not exceeding the permissible compression.

b) Maximum shear stress in the spring in the normal condition should not exceed the permissible shear stress and in earthquake condition should not exceed torsional yield strength. Shear stress for above cases are calculated by following formula.

Maximum shear stress with horizontal force L on spring

$$= (Lh_s + VR) \frac{16}{d^3} \left(\frac{4C-1}{4C-4}\right) + \frac{16PR}{d^3} \left(\frac{0.615}{C}\right), \text{ where } C = D/d \qquad \ldots (4)$$

Shear stress with no horizontal force on spring is calculated by putting L = 0 in Eqn. 4.

c) The conventional supporting structure is strong enough to take the vertical load and moment due to inertia force and additional moment due to P - effect.

CONCLUSIONS

1. Cantilever type of supporting structure are recommended for the sites where maximum ground acceleration in vertical direction is not high.

2. Method of designing isolation system for switchyard equipment capable of transimitting controlled horizontal and vertical accelerations in equipment is presented.

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TABLE 1 - EQUIPMENT DATA AND DESIGN DETAILS OF ISOLATION SYSTEM

Particulars	NAME OF EQUIPMENT				
	Current Transformer Type A	Current Transformer Type B	200KV Capacitor Voltage Transformer	200KV Potential Voltage Transformer	200KV Ligtening arrester
We (kg.)	880	1100	800	680	450
He (m)	3.24	3.24	3.49	3.0	4.2
a (m)	1.08	1.08	1.16	1.0	2.1
Wa (kg)	1500	1000	1500	1500	1500
N*	4	4	4	4	4
D (m)	0.5	0.5	0.5	0.5	0.5
hu (m)	0.85	0.85	0.85	0.85	0.85
hs (m)	0.60	0.60	0.60	0.60	0.60
n	6	6	6	6	6
A (m)	1.0	1.0	1.0	1.0	1.1
d (cm)	3.6	3.5	3.6	3.6	3.5
Kx(kg/cm)	21.70	19.40	21.70	21.70	19.40
Ky(kg/cm)	21.70	19.40	21.70	21.70	19.40
T (sec.)	1.05	1.04	1.03	1.005	1.006
Sah (cm/sec^2)	0.43g	0.43g	0.43g	0.46g	0.46g
Sav (cm/sec^2)	0.215g	0.215g	0.215g	0.23g	0.23g
V (kg)	595	525	575	545	488
L (kg)	298	263	288	273	244
τ_1 (kg/cm^2)	3852	3691	3710	3528	3439
τ_2 (kg/cm^2)	1790	1748	1730	1640	1592

* No. of springs

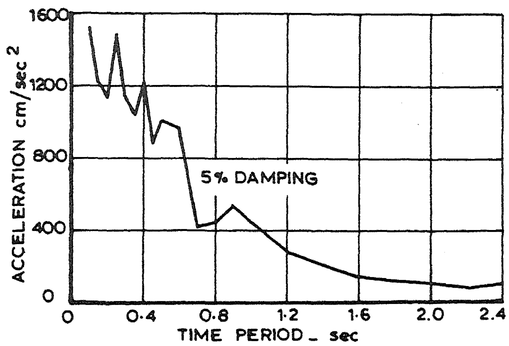

Fig.1 _ Acceleration spectra

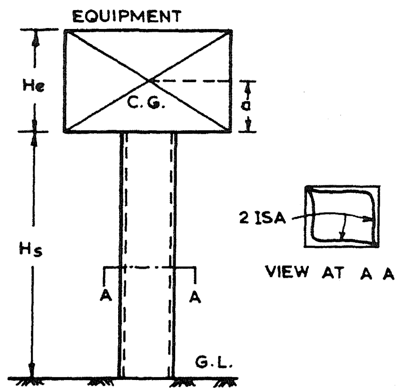

Fig. 2 a _ General arrangement of cantilever type supporting structure

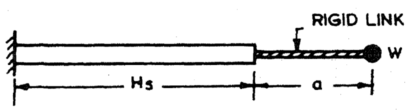

Fig. 2b _ Idealized single degree freedom system of cantilever type supporting structure

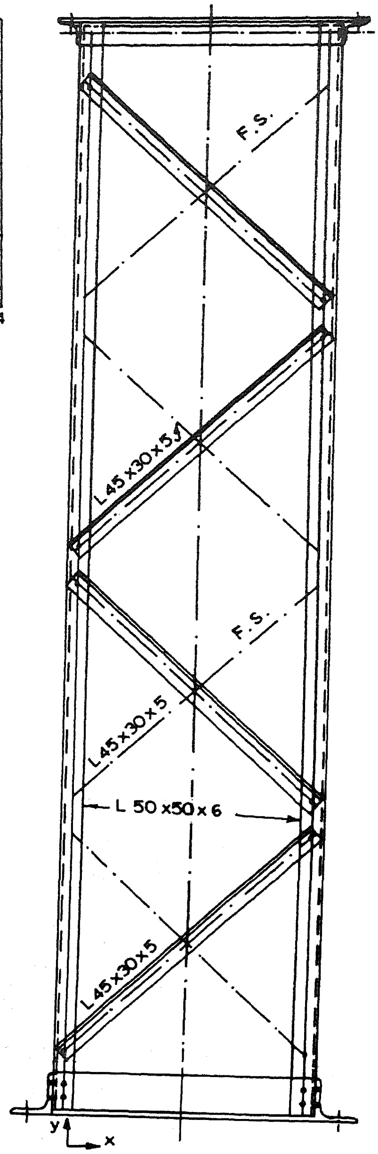

Fig. 3 _ Configuration of conventional type of structure

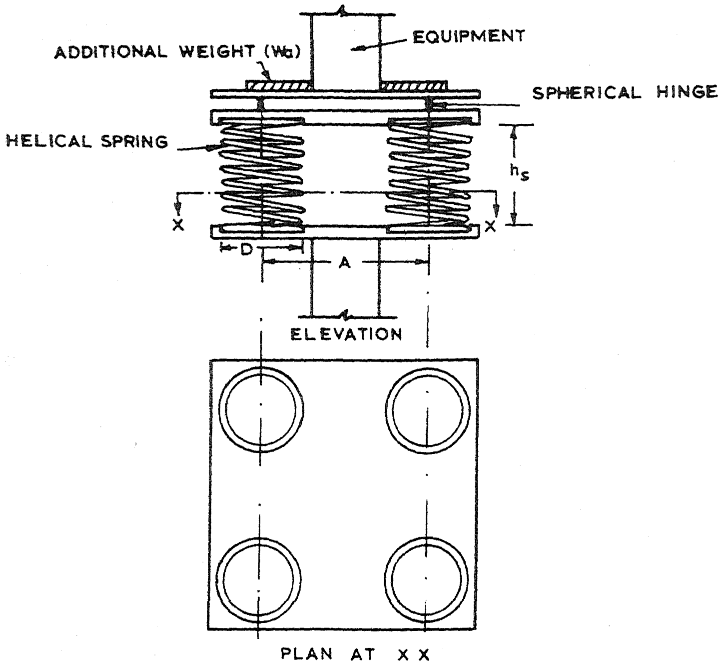

Fig. 4 _ Details of Isolation system

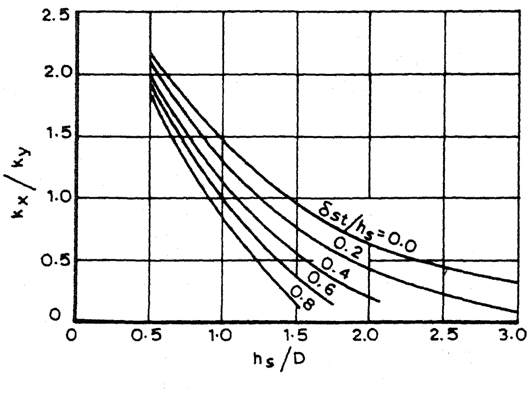

Fig. 5 _ Ratio of k_x/k_y as a function of h_s/D and the ratio of δ_{st}/h_s