Seismic Design and Qualification of Cable Trays in Nuclear Power Plants

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SUMMARY

In nuclear power plants cable tray systems which serve as support systems for electrical cables with safety related functions have to be seismically designed. The structural integrity has to be remained during dead weight and seismic loadings.

Cable trays are light equipment components. They consist of steel ladder type cable trays and a support system. In case of horizontal cable trays, the trays are supported by cantilevers clamped to standard struits with e.g. I80 cross-section. The struits are restrained to the building structure by anchor or dowel plates.

The seismic approach presented here is accomplished by a combination of analysis and experiment. The dynamic analysis concerns the anchor loads at the interconnection of support and building, the stresses of the struits and the responses of the cantilevers. The dynamic tests reveal the maximum load carrying capacity of the cantilevers and the steel ladder type cable tray.

Compliance with the requirement to withstand dead weight and seismic loading is reached by comparision of analytical responses with responses of the dynamic tests.

1. INTRODUCTION

In nuclear power plants cable trays which are threedimensional runing systems and which support safety related electrical cables, have to be seismically designed.

A common approach to meet these requirements, replaces the dynamic loads by static ones and performs an elastic analysis. This practice quickly leads to structures with relatively massive cross-sectional areas.

In order to preserve the cable trays as light equipment component and to insure their functional integrity during dynamic loadings, a combination of dynamic analysis and experimental testing seems to be appropriate.

The proposal of an analysis-testing combination can be found in references /1/ and /2/. Normally the experimental investigations are carried out as static load tests and serve to determine the extreme load carring capacity of the steel ladder tray.

On contrary to this the experiments performed here were dynamic load tests and concerned the cantilever beams that support the ladder typ tray including various connection elements. The tests served to find the extreme dynamic responses in function of dynamic excitation.

The model of the dynamic analysis is restricted to the supporting elements of the tray system. This implies standard struits as well as cantilever support beams. The struits are restrained to walls, floors or ceilings by dowel or anchor plates.

The question still remains, how to combine the analysis with the experiment. This is simply realized by comparision of the cantilever's dynamic responses of both the analysis and the testing.

Futher more an eye is kept on the global dynamic motion of the tray system. The fact that the trays are horizontally connected with each other is often neglected. This can lead to uncontrolled rearangements in the struits and in the reaction forces of the restraints. This problem is solved by develloping special criteria that allow to decouple the tray runs into specified sections.

2. DESCRIPTION OF CABLE TRAY ELEMENTS AND DESIGN PARAMETERS

2.1 CABLE TRAY ELEMENTS

The main elements of the cable tray system consist of

- restraints such as dowel-, bolts- or anchor plates
- standard struits with I 80 or MSH 80 x 80 cross section
- cantilever beams with [-Profil. The length varies within 200 mm and 800 mm, the wall thickness within 2 mm and 3 mm. The cantilevers are connected to the struits by clamping. This allows to adjust the canti-

levers anywhere along the struit axis.

- steel ladder typ tray with side rails of ⊏-profile and rungs of ⊔-profile. The ladder tray is equiped with diagonal bracings in its plane. The cantilevers and trays have bolted connections. The width of the tray varies within 200 mm and 600 mm.

2.2 DESIGN PARAMETERS

The design parameters are

- cable load density of 70 kg/m
- spacing of struits with maximum support length of 2,3 m for tray width of 600 mm and of 2,5 ÷ 2,7 m for smaller tray widths.
- special requirements for spacing of dowels
- the distance between the trays along the vertical axis of the struits lies within 200 mm and 300 mm.

3. DESIGN CRITERIA

3.1 DAMPING VALUES

The damping values of the cable tray system influence importantly the design because this is an input parameter for the dynamic analysis.

Damping results partly from the steel construction and partly from the electrical cables. An appropriate damping value for the steel construction is about 4 % of critical damping. The damping of the cables is due to friction effects which are mass proportional. This leads to increasing damping the more the cables are oscillating.

This effect was measured experimentaly. The result is displayed in Fig.1.

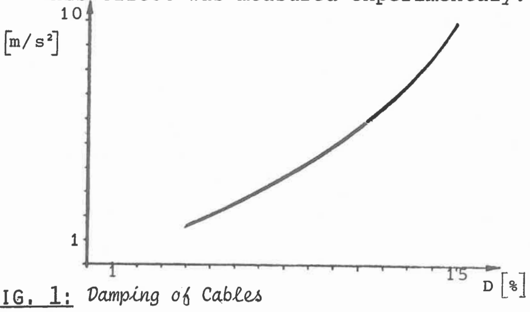

FIG. 1: *Damping of Cables*

The response spectra commonly used are suited for systems with constant damping. They have to be modified because of the fact that cable tray systems dispose of variable damping.

First, the response spectra are prepared in such a way that the presentation of frequency and damping is changed. Response accelearation now appears as function of damping with frequency as diagramm parameter. The parameter curves in this new diagramm are intersected with the cable's damping curve. The intersection points yield the modified response spectra which is then used in the dynamic analysis.

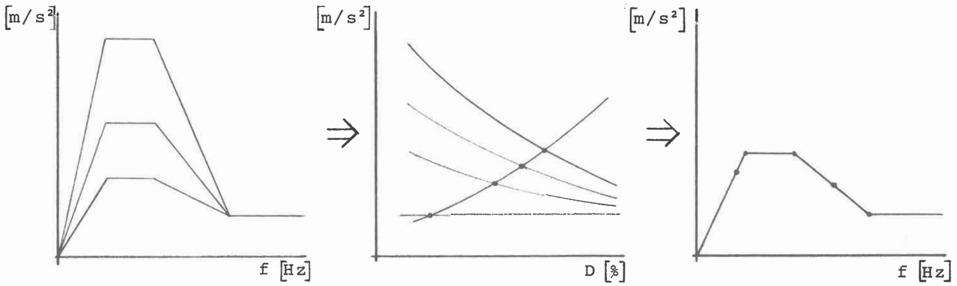

FIG. 2: *Procedure to derive modified response spectra impling variable damping*

3.2 GLOBAL DYNAMIC MOTION

Cable trays are usually running in very miscellaneous threedimensional shapes.

There are sections where tray runs are grouped together or where they are branching off or crossing each other. In other sections of the tray run the boundary conditions of the supporting system change, i.e. cable trays supported by struits fixed to walls pass over to struits anchored to ceilings, etc.

Therefrom it is obvious, that the cable tray's motion depends on the local as well as on the global supporting conditions which have to be taken into account in the qualification method.

3.3 ALLOWABLE LIMITS AND FUNCTIONAL INTEGRITY

Supports and struits are designed within elastic limits. In case of dynamic loadings the yield point of these elements may not be exceeded.

The cantilever beams and the steel ladder trays may undergo some plastic deformation after seismic excitation. At any case the functional integrity of the system has to be assured. This concerns the clamping connection between the cantilevers and the struits. The cantilevers and the tray system are allowed to deform plasticly within prescribed limits.

4. QUALIFICATION METHOD

As mentioned before the evidence of being sufficiently seismically equiped is given by a combination of analysis and testing.

4.1 EXPERIMENTS

Cantilevers and trays are mounted on a shaking table. The trays are loaded with weights equivalent to the design load density.

The tests are suited to reveal the rigidity properties of the tray such as connections between side rails and rungs or between side rails and diagonal bracings as well as the splicing element between tray segments. Further more the testing shows if the friction of the clamping procedure is sufficient to withstand dynamic loading. These effects can't be modelled in any analysis.

Different test specimen are investigated, e.g. straight spliced or curved tray runs with various support spacings, T-segments with branching off, etc. (see Fig. 3 and 4).

At first, a frequency search test is performed at low excitation level. In the following the table shakes sinusoidaly with sweeping frequency. The frequency varies within a closed cycle with maximum frequency of 100 Hz. The exitation is enhanced stepwise so long as failure happens. Failure of system means that the requirements of functional integrity are violated (see Fig.5 and 6).

The testing results in gaining maximum responses of the various test specimen just before failure occurs. These are admissible responses that have to be weighted with a safety factor later on.

Because of the fact that failure can be due to many reasons the response acceleration at the free end of the cantilever is regarded to be a characteristic response in place of all responses of the tray system. This is always done independently if the cantilever or the tray fails.

4.2 ANALYTICAL METHODS

The analytical approach employs simple beam type finite elements which model one struit with belonging cantilevers and masses (see Fig. 7). The dynamic analysis is carried out with commercially available computer software such as "STARDYNE", etc.

As can be seen from Fig. 7, the ladder tray is not explicitly modelled. Implicitly, the stiffness properties of the tray in longitudinal and transverse direction which are known from the experiments, are incorporated into the model by coupling and suppressing degrees of freedom. The mode shapes of the beam model are equivalent to those of the actual cable tray system.

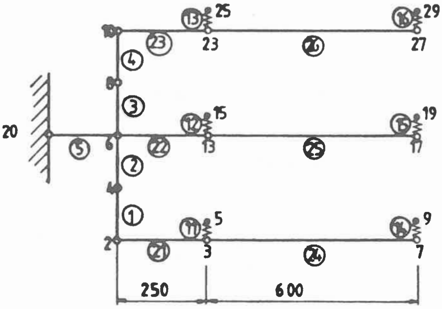

FIG. 7:
Moddeling of trays, cantilever and struit fixed to wall

In function of cable mass and support spacing the flexibility of the side rails must be considered. This is simply done by adding a spring element. The spring constant yields the fundamental frequency of the ladder tray known from the dynamic tests.

The results of the dynamic analysis are reactions loads, stresses in the struit and response acceleration at the free end of the cantilever.

The reactions lead to the design of the dowel-, bolts- or anchor plates. The stresses determine the wall thickness and the weld of the struit. The functional integrity of cantilever and ladder tray is maintained during and after dynamic loading if the calculated response accelerations prove to be less than the allowable ones.

5. DESIGN REGUIREMENTS

It seems to be obvious that the proposed qualification method has to agree with the practical design and vice versa.

To achieve this, the definition of a "uniform" tray run is created and which is demanded to fulfil the following requirements:

- within a tray run of more than one segment only one typ of tray support may be used
- the boundary conditions of the supports may not alter
- the geometry of supports may vary within prescribed limits only
- the cross-sectional areas of the supporting elements remain constant.

These demands guaranty the equivalence of dynamic properties of all elements within a "uniform" tray run. Uncontrolled rearrangements in stresses or in reaction forces are excluded.

In practice design it will be certainly impossible to fulfil these four requirements for every tray run within a building. In case of violating one of the four demands the tray run has to be decoupled into sections in such a way that every single section meets the "uniform" tray run definition.

An other method to reestablish "uniform" tray run is to install diagonal brachings between the supports along the longitudinal direction of the tray run. This step can be suitable to ease point No. 2 and 3 of the requirements.

"Decoupling" of trays means cutting tray's side rails. Especially this measure is taken at

- branching of T-segments
- intersection points where crossing trays possess one common support
- large curved trays which are supported somewhere in the middle.

In Fig. 8 an example of decoupled tray runs is displayed.

Finally, it may be emphasized that the decoupling procedure proved to be advantageous in practical design. It was noticed in the nuclear power plant *Mülheim-Kärlich* that mounting of the tray system became easier and more economical because planning and installation times were reduced.

REFERENCES

/1/ SHAHIN, R.M. et al.: "Seismic Analysis and Design of Electrical Cable Trays and Support Systems", Nuc. Eng. Desgn. 45 (1978) p. 515-522.

/2/ SKOLNICK, E. et al.: "A method for Seismic Qualification of Cable Tray Systems in Nuclear Power Plants", IEEE Trans. Power Apparatus Systems, Vol. PAS-98, No. 4 July/Aug. 1979.

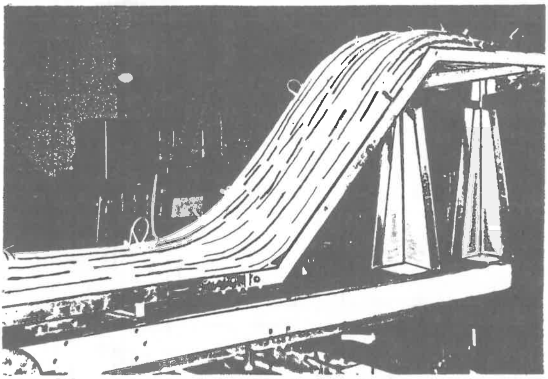

FIG. 3 :

Test specimen of ascending segment

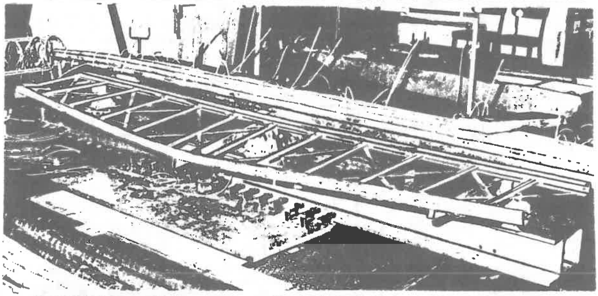

FIG. 4 :

Test specimen of straight tray run

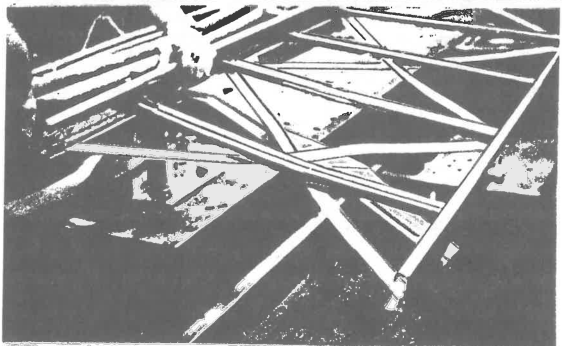

FIG. 5 :

Damaged cantilever and tray after dynamic loading

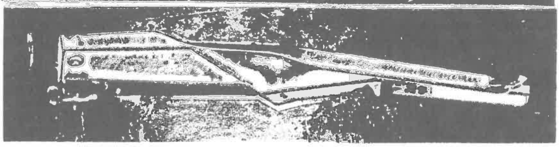

FIG. 6 :

Buckling of cantilever

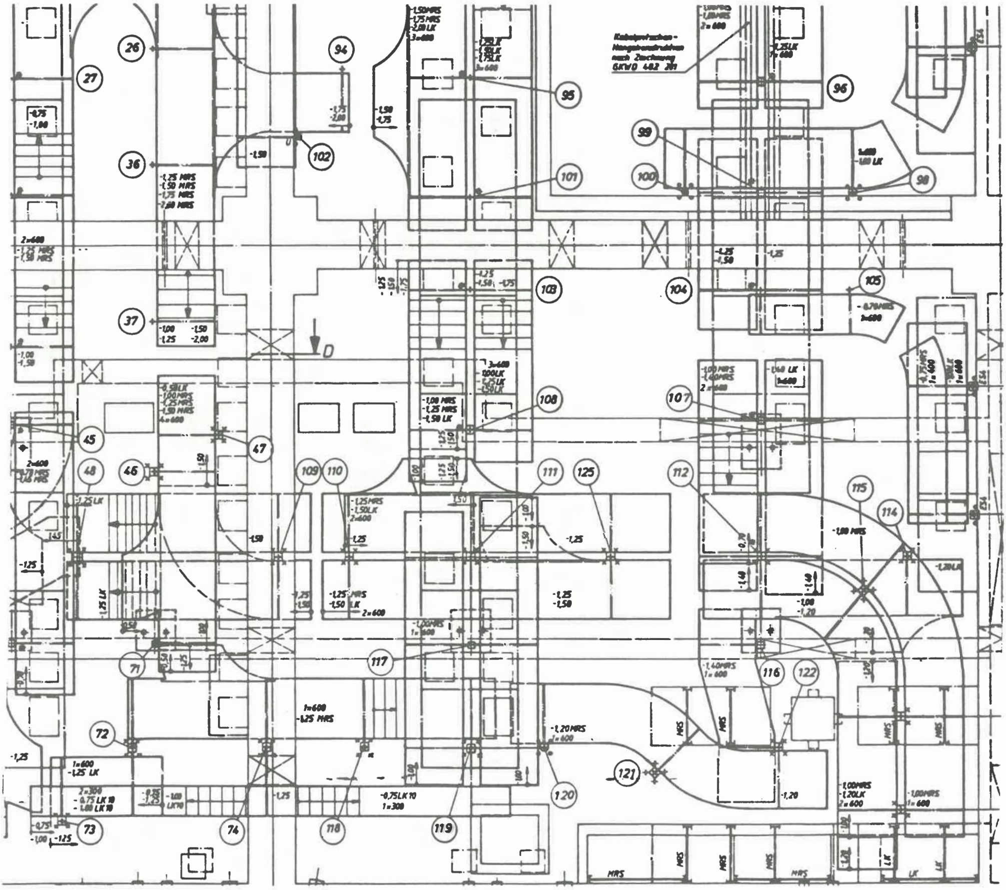

FIG. 8 : *Decoupled tray runs*