

DESIGN OF PREQUALIFIED SUPPORT SYSTEMS SUBJECTED TO DYNAMIC LOADS

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This paper describes an approach for the design of prequalified system supports under dynamic loads. System supports in Safety-Related buildings of Light Water Reactors have to be designed to provide structural integrity during and following a dynamic event. The loads that such a system must be designed to withstand are Dead Weight, Thermal, Seismic and in addition, for Boiling Water Reactors, Safety Relief Valve blowdown loads have to be considered. To demonstrate the merit of the proposed approach we have chosen the HVAC duct work and their supports as a representative system. An acceptable method to dynamically qualify such a support system is to simulate it as a multi-degree-of-freedom model, similar to the conventional approach of idealizing a piping system, which can then be analyzed using either a response spectra or a time-history technique for analysis of the dynamic effects.

The present method is one that prequalifies the system supports and ducts for a certain acceleration level by decoupling the two systems. This approach preselects the maximum spacing of the support system such that the supporting duct-work including their accessories, will respond in the high or rigid frequency range of the building dynamic response. In addition, the system supports are designed to respond in the rigid frequency domain, thus, eliminating the interaction effects between the two systems. This also ensures that the dynamic response of the decoupled systems are equivalent to that of the combined coupled system.

In the present approach rectangular ducts are considered and two typical hanger configurations are analyzed. For each of these configurations three or four typical structural angle members are selected with a combination of hanger member leg lengths, hanger depth, and width. The latter two parameters represent the duct dimensions. Each of the parameters above are varied in our analysis and a frequency analysis is performed using a standard computer program. The hanger load capacity is determined using a frequency controlled design which is the basis for design of the structural members and connections. In addition to the dynamic effects transverse to the duct run it is essential to consider dynamic effects along the duct run. The loads in this direction are transferred using a system of longitudinal cross or K-braces spaced at preselected intervals along the duct axis. Further consideration is given in the design, for duct to hanger connection for transferring shear loads into the hanger system.

Furthermore, the capacity of the support system can be increased by a factor of two or more with a slight system design modification. This can be done by introducing internal cross bracing, using a structural bar member, within the duct, and, along the duct run at each support location. This has been shown to increase the lateral rigidity of the support assembly and thus increases its load carrying capacity. Further, it can be shown that, the slight restriction in air flow and drop in pressure due to the internal brace if oriented properly does not result in a change in duct dimensions for large ducts.

The results of the analysis, are presented in the form of load tables and charts which are developed for various structural member sizes which are commonly used, and standard configurations of support systems with a predetermined load capacity under dynamic loads. The convenience of using prequalified system supports for a given duct size results in considerable saving in engineering manhours and computer time that would otherwise be necessary if each system were designed uniquely. This design-analysis method, provides a convenient tool, and is an optimal method for establishing the reliability of component supports without undertaking a rigorous case by case design effort.

In conclusion, the above approach for the design of a prequalified safety-related support system, can be extended to other component supports such as, cold piping, cable trays, heaters and coolers, instrument racks, etc. In such a design approach consideration should be given to establish an appropriate mass, frequency ratio and stability criteria between the supporting and supported components.

1. Introduction

This paper presents a new approach for standardizing the design and spacing of the supports for safety-related systems in Nuclear Power Plants. Extensive analytical work was done to encompass several typical cases in an attempt to obtain a prequalified support to be used in a range of application. In nuclear power plants, supports for safety related systems are designed, to provide structural integrity during and following a Safe Shutdown Earthquake event. Some of the major loads that such a system must be designed to withstand are Dead Weight, Thermal, Seismic and in addition, in Boiling Water Reactors, Pool dynamic loads have to be considered. In this paper we have chosen the HVAC ductwork and its support system to demonstrate the feasibility of such a dynamically prequalified design approach. It should be pointed out that there are portions of this system whose continued function is not required during an earthquake, however its failure could reduce or impair the function of another safety-related system. Therefore, it is essential to design the support systems as safety-related, Seismic Category 1.

In the past it has been common practice to design each support system on an individual or unique basis and then account for interaction between the supported system and supports. Such an approach is tedious and very time consuming. Furthermore, it results in a wide variation of design details which complicates detailing, fabrication and field erection. This paper, therefore, endeavored to standardize the design process with the following objectives:

- 1) To develop a consistent design for connections, interfaces, etc. for safety-related duct systems and their supports.
- 2) To establish generic design tables for support spacing, for various standard duct dimensions and gauges.
- 3) To establish generic design tables for hanger load carrying capability, for two typical hanger configurations, types 1 and 2 represented in Figure 1. For design purposes the three variables considered are X, W and H and, due to practical considerations limits are set on the maximum values of these variables as shown in Figure 1.
- 4) To establish the load capability tables mentioned in 3 above for a few typical structural member sizes, used uniformly for all hanger members in the standard support design.
- 5) To provide methods for optimizing the amount of structural steel required to assemble an individual support system.

2. Design Philosophy

For any physical layout of a ductwork and its supports, one method of analysis is to simulate the system as a multidegree of freedom three-dimensional system. A dynamic analysis performed on such a system would require

a significant amount of engineering effort and computer time. This provides the only rational basis for the design of a flexible-flexible assembly by accounting for interaction effects. The general options available for design are as shown in Table 1. The design philosophy presented here, is based on option 3 which is referred to as a "Frequency Controlled Design Basis." It should be mentioned that the threshold of rigidity has to be established at the outset and in this analysis approach it has been set at 33 Hz. The maximum spacing of the supporting system is determined or preselected such that the supporting ductwork and their accessories respond in the high or rigid frequency range. In addition, the support systems are designed to respond in the rigid frequency domain, thus eliminating the interaction effects between the two systems. By decoupling the systems and their supports and designing them independently as rigid structures, it is evident that the combined response is equivalent to that of the response of the coupled system.

In this paper the analysis method to determine the maximum feasible support spacing based on the above mentioned philosophy will not be covered, since, Reference 1 provides comprehensive documentation for this. However, the conclusion is that for most commonly used duct sizes and recommended duct gauges a support spacing of approximately fourteen feet qualifies the ducts as rigid systems, provided the supports are rigid.

To maximize the rigidity of the system supports, the member joints are designed as welded connections, with due consideration given to transfer shear loads transmitted along the duct axis into the hangers. The two methods commonly used to transfer loads along the duct axis are by using either a system of longitudinal cross or K-type braces at preselected intervals along the duct run. These members have been selected as rectangular bar sections, refer to Figure 2, which are designed as tension members and sized on the basis of the maximum load to be transferred versus their load capacity in tension. The compressive load component from each set of brace is transferred into the adjacent vertical hanger members at each restraint location. In addition, loads are transferred from the ducts, into the support system, through stitch welds along the duct perimeter at each hanger location. Figure 3 shows recommended configurations for duct to hanger stitch welds which requires a minimum of two side duct to hanger contact.

3. Method of Analysis

The duct support systems were idealized to fall under two categories as shown in Figure 1. The parameter 'X' defined as the hanger leg length was assumed to vary from 1' to 5' for Hanger designated as Type 1, and from 6' to 7' for Hanger type 2. The two other variables of concern are W and H which are dependent on duct dimensions most often used in the power plant.

Computer idealization of the two basic hanger types is done by simulating the members as 3-D beams, having both bending and axial resistance, with duct and accessory weights idealized as uniform weights along the top and bottom horizontal members. A frequency evaluation is performed using

the SAP IV computer program (Reference 2), to determine the lowest system frequency. In addition, a static analysis is performed using the same computer model and appropriate dynamic load factors, (these are determined using the building dynamic response characteristics, Reference 3,4) to determine joint forces and moments. These forces and moments corresponding to the hanger capacity loads determined from the frequency analysis, are used for the design of the hanger to attachment connection and for the design of the welded joint connections of the standard system (Reference 5).

Since we are interested in calculating the capacity of the hanger such that the system's fundamental frequency is 33 Hz or higher, it is a simple task to tune the system load, up or down as required, such that the hanger response is in the rigid range.

To establish the relationship between the hanger load carrying capacity and the dynamic characteristics of each hanger type, a scaling technique utilizing the modal, for a one degree-of-freedom system has been used. Mathematically:

$$f_c = \frac{1}{2\pi} \sqrt{\frac{K_c}{M_c}} \quad (1)$$

where f_c , K_c are the computed frequency, and stiffness respectively, for the particular hanger type under consideration, and M_c is a predicted hanger load capacity, assumed in the computer modal analysis which corresponds to the duct and accessory mass.

To assure that the fundamental frequency is equal to or greater than 33 Hz., the following must be satisfied:

$$f_{\text{reqd}} \underset{\text{below}}{\geq} 33 = \frac{1}{2\pi} \sqrt{\frac{K_c}{M_{\text{cap}}}} \quad (2)$$

In equation 3 $\uparrow M_{\text{cap}}$ is the hanger load carrying capacity which assures a frequency of 33 Hz, and is obtained from equations 1 and 2.

$$M_{\text{cap}} = \left(\frac{M_c}{\left(\frac{33}{f_c}\right)^2} \right) \quad (3)$$

It should be noted again that the above expression is only valid if the hanger and duct systems do not interact and they can be analyzed as decoupled-systems.

4. Parametric Study and Results of Analysis

Based on the above model formulation, load capacity tables have been developed for different structural members and hanger types, using W, H and X as variables in the hanger frequency evaluation, and the corresponding hanger load capacity calculations. A representative chart for 3x3x $\frac{1}{4}$ " members and a maximum H = 30", is shown in Table 2.

Since the object of this analysis is to design a support system which is stiff and at the same time does optimize on the total weight of steel to be used, tables are developed to help the designer to select a hanger type, and the member size for the load carrying capability required. These tables have been developed to account for a certain magnitude of building response accelerations, such that the stresses in the members, joints, hanger attachment and duct to hanger stitch weld are still within allowable stress limits. Standard details have been developed for all member joints and typical hanger attachments such as embedment plates, auxiliary steel, etc.

To increase the load carrying capacity of the system supports, studies were made to in-

investigate the effect of introducing a rectangular bar member, approximately $2 \times \frac{1}{4}$ " in size, inside the duct in the plane of the supports (See Figure 4). This investigation showed that the hanger load carrying capacity may be more than doubled as a result. Another advantage observed was that the size of the structural members of the support could be reduced, without affecting the support capacity if this internal cross bracing is utilized. Furthermore, a three-dimensional computer analysis was set up, idealizing, the hanger, duct and internal brace to study the installation tolerance of this internal cross brace. It was shown that a ± 6 " deviation between the plane of the cross bracing and plane of the hanger would have insignificant effect on the calculated load carrying capacity. Table 3 shows the hanger capacity chart for the case of $1 \frac{1}{2} \times 1 \frac{1}{2} \times \frac{1}{4}$ " members with $2 \times \frac{1}{4}$ " internal duct brace and $H = 30$ ". A comparison of Tables 2 and 3 shows that for $X = 5'$ and $W = 60$ ", the load capacity ratio is approximately equivalent, whereas, for $X = 3'$ and $W = 60$ " the load capacity ratio is approximately in the ratio of 1 to 2, for $3 \times 3 \times \frac{1}{4}$ " members without internal duct braces and $1 \frac{1}{2} \times 1 \frac{1}{2} \times \frac{1}{4}$ " members with internal duct braces. This results in a significant material and overall cost savings in the design of such support systems.

5. Conclusions

The methodology presented for a 'frequency controlled' design approach for dynamic pre-qualification of system supports, in power plants, is quite promising.

It is worth mentioning that the design approach presented has utilized many important considerations for the supporting structure and the supported components, such as:

- 1) Determining an appropriate ratio for mass, frequency and a stability criteria.
- 2) Transferring loads from one system to the other by designing a system of axial restraints and stitch welds between duct and hanger.
- 3) Providing means to determine the maximum load capacity of the supports, thus estimating the excess available capacity after accounting for the supported ducts and accessories. The excess capacity can then be utilized to support additional components.

Additional research is required to study the energy absorbing capacity of the ductwork, locally around the support systems, with emphasis on local buckling and warping of the ducts.

This approach has been extended to the qualification of supports for other safety-related systems such as Heater, Cooler and Fan supports. The results of such an analysis is, material optimization, savings in engineering and computer time, and a uniform design approach which reduces fabrication and erection time and costs.

6. Acknowledgement

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TABLE I
DESIGN OPTIONS AVAILABLE

Options	Hanger Support System	Ductwork	Remarks
1	Flexible	Flexible	3-D Analysis Required to account for interaction effects. Stress Controlled Design.
2	Rigid	Flexible	3-D or Pseudo 3-D Analysis required to account for interaction effects. Stress Controlled Design.
3	Rigid	Rigid	Frequency Controlled Design. 2-D Analysis required. Stress Analysis to verify member stresses.

TABLE II

HANGER LOAD CAPACITY IN POUNDS FOR $3 \times 3 \times \frac{3}{8}$ " L'S
FOR MAXIMUM H = 30"

HANGER LEG LENGTH X IN FEET

HANGER WIDTH W IN INCHES	Type 1					Type 2	
	1'	2'	3'	4'	5'	6'	7'
	24	615	580	510	410	320	390
30	625	595	570	470	400	430	375
36	630	610	590	530	450	460	410
42	630	615	600	550	490	490	440
48	635	620	610	565	520	505	470
54	635	620	610	580	535	520	485
60	630	620	610	590	550	530	500

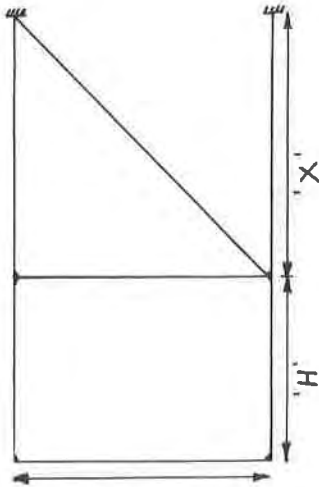
TABLE III

HANGER LOAD CAPACITY IN POUNDS FOR $1 \frac{1}{2} \times 1 \frac{1}{2} \times \frac{1}{4}$ " L'S
FOR H = 30" WITH $2 \times \frac{1}{4}$ " INTERNAL BRACE

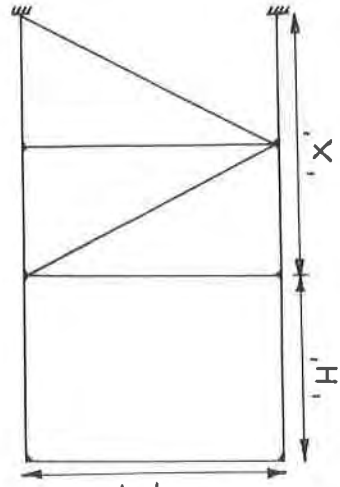
HANGER LEG LENGTH X IN FEET

HANGER WIDTH W IN INCHES	Type 1					Type 2	
	1'	2'	3'	4'	5'	6'	7'
	24	1570	940	520	290	170	190
30	1830	1150	720	440	275	265	210
36	1930	1340	880	560	370	340	260
42	1950	1450	1000	660	460	410	305
48	1930	1505	1100	750	540	470	350
54	1860	1520	1150	810	600	515	395
60	1750	1480	1170	860	640	560	440

FIGURE 1
HANGER TYPES



TYPE 1: $X \leq 5'$ 'W'



TYPE 2: $6' < X < 7'$ 'W'

"X" denotes hanger leg length

"W" denotes hanger width

"H" denotes maximum dimension of duct height

Due to practical considerations, for design application, the maximum range for "X", "W" and "H" shall be : $X \leq 7'-0$; $W \leq 96"$; $H \leq 60"$

FIGURE 2

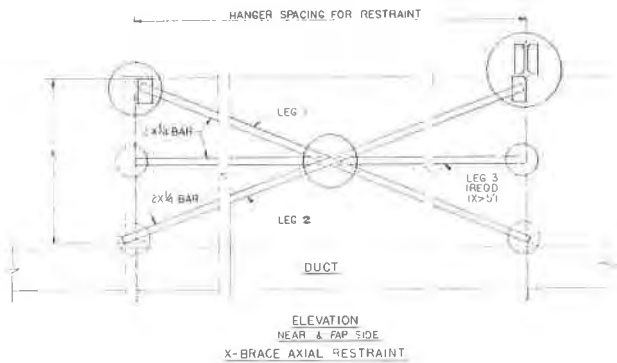
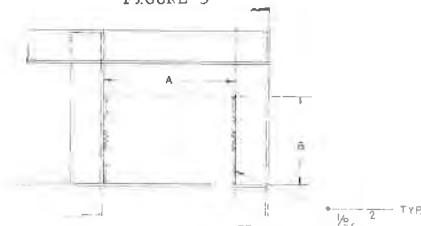
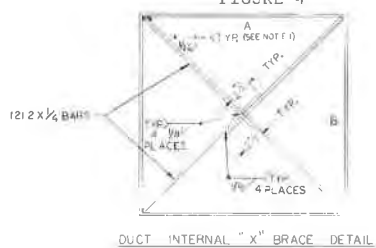


FIGURE 3



RECTANGULAR DUCT TO HANGER WELD DETAILS

FIGURE 4



DUCT INTERNAL "X" BRACE DETAIL