SEISMIC ANALYSIS OF A NUCLEAR CONTAINMENT POLAR CRANE

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SUMMARY

The seismic analysis of a nuclear containment polar crane is discussed including analytical methods and specific problems relating to the nature of the seismic loading of structure having support conditions typical of crane structures. Without positive restraints, a nuclear containment polar crane is in contact with the containment vessel only through the wheels in contact with crane runway rails. In the direction normal to the crane bridge girders, the crane has rolling supports while in a direction parallel to the bridge girders support is provided only by the frictional forces acting at the wheel/rail interface. Since this latter force transfer mechanism is frictional in nature, it is dependent upon a vertical force which depends upon the combination of dead load, vertical seismic load and other vertical live loads considered for the design criteria.

Owing to the frictional and rolling support of the crane wheels, the seismic response of a polar crane becomes non-linear allowing both rigid body and elastic modal response to seismic excitation. Since the seismic loading of a polar crane arises from support motion, we must consider the question of whether the structural integrity of a polar crane is enhanced or degraded by the use of positive load transfer mechanisms which affix the crane to the rails.

Since the crane is operational only during a plant refueling period, a unique parking position for the crane may be assigned, thereby simplifying the design of restraints to retain the crane on the rails during a seismic event. Discussions are presented on the probability of a seismic event occurring during crane operation when the crane would not be positively affixed to the rails. It is shown that the probability of an SSE occurring during crane operation is exeedingly small. Similar considerations are made for the OBE which led to secondary support devices designed to prohibit the crane from falling from the rails as a rigid body.

The seismic analysis of the polar crane was performed using a finite element model comprised of three-dimensional beam and flat plate elements using the response spectra technique to determine the SRSS internal forces, moments and stresses. A total of nine response spectra, arising from the coupled response of the containment structure were incorporated into design response spectra for the analysis. Details of both the finite element modeling and the analysis are discussed.

As a Class I nuclear structure, the primary design objective was to prohibit either total structural collapse or falling from the rails without structural collapse. The latter problem was resolved through the use of positive restraint mechanisms based on the above considerations. In the evaluation of the stresses, no single design code was found to be directly applicable. Therefore, a discussion is presented that resulted in the combined use of the American Institute of Steel Construction code, Crane Manufacturers Association of America Specification No. 70, and DIN4114.

1.0 INTRODUCTION

A seismic analysis of a typical nuclear containment polar crane, shown on the plant layout on Fig 1, was performed using finite element discretation and modal analysis techniques. While this appears to be an efficient computational approach, a number of engineering assumptions and a degree of judgment are involved in the practical application of the method and in the interpretation of the results. The objective of this paper is to highlight these assumptions and to discuss the interpretation of the results as they relate to design.

2.0 SEISMIC STRESS ANALYSIS

2.1 Finite Element Model

The polar crane, shown conceptually on Fig 2, can be considered as two main substructures--a bridge and a trolley. The bridge consists of two box girders, railway trucks or bogies at each end, end ties, and mechanisms for rotating the bridge. The trolley travels atop the bridge and supports hoisting and traversing mechanisms. The finite element models of the bridge and trolley are shown on Figs 3 and 4, respectively.

The main box girders were idealized as a series of three-dimensional beam elements capable of bending, shear, and torsional (St. Venant) deformations. The mass of the box girders including stiffeners and attached mechanical equipment was included by using a combination of consistent and lumped mass matrices.

A more precise model of the main girders would reflect essentially non-linear effects such as due to local buckling or shearing distortions of the cross-section. The first effect can be neglected assuming that the plate girder stiffener design is such as to prevent local buckling. Considering the closed cross-section of the bridge girders and conservative stiffener design, a more precise idealization of the girders is unnecessary.

The element size for the main girders was selected based on preliminary estimates of the fundamental frequency of the system and requirements to model tapered sections of the girders.

The wheel bogies are normally constructed in a rigid manner but significant compliance may result from wheel bearing deformations. The wheel bogies were treated as separate substructures and an associated stiffness matrix was derived using the finite element model shown on Fig 5. The resulting stiffness matrix was then used as part of the global model. This approach includes the gross effect of compliance of the bogie frame without significantly increasing the size of the model. Similarly, the compliance of the crane runway support system was included in the model by a representative stiffness matrix.

The trolley frame was modelled using beam elements and the same assumptions apply as mentioned for the bridge girders. For horizontal loads, the trolley frame is significantly stiffened by a steel deck. This effect was included by idealizing the deck with flat shell elements rigidly attached to the trolley frame. Significant masses of mechanical equipment were lumped at their geometrical location and linked rigidly to the trolley frame. Equipment which was flexibly supported such as the hoisting cable drums were also idealized using beam elements. Our experience indicates that the model of the trolley should only include lumped equipment masses and details to a degree compatible with the global model of the polar crane. Inclusion of very small masses can often result in numerical ill-conditioning and unreliable results.

2.2 Support Conditions

Proper idealization of support conditions of the bridge upon the crane runway wheels and of the trolley upon the bridge is of paramount importance in determining the dynamic response of the polar crane. In the absence of other restraints, the crane and trolley are supported on flanged railway wheels. Movement of the wheel upon the support is essentially controlled by friction and limited only by wheel flanges. The response of a structure driven by Coulomb friction from a randomly moving support is discussed in Ref [1]. It is apparent that the potential relative displacement of the wheel and rail is much greater than the usual gap provided between rail edges and rail flanges.

As a first approximation, the wheels were treated as rigidly restrained to the rails. This established preliminary design loads for seismic restraints which were determined to be necessary to assure the structural integrity of the polar crane during the SSE. Once a preliminary design of a positive restraint connecting the bridge girder to the rail was complete, the analysis was repeated and the exact details of this restraint system were incorporated into the finite element model. Seismic loading at this elevation of the nuclear containment is severe enough that it is unlikely that typical bogie designs could withstand the resultant horizontal loading without significant reinforcement. In fact, without additional restraint it is conceivable that the wheels could intermittently lift free of the crane rail.

As the polar crane is operational only during a plant refueling period it may be assumed, based on probability analysis, that the crane has been parked in a predetermined position during occurrence of the Safe Shutdown Earthquake. On this basis, a number of different schemes are conceivable for design of the polar crane bridge restraints. The first alternative shown on Fig 6A is perhaps the most economical. The function of the restraint, which must be designed for impactive loads, is only to limit the total relative displacement of the bridge and its supports. For the SSE, the only requirement is that the crane remain upon its supports. Rigorous analyses would require solution of a non-linear problem using a time history of the support motion. On the other hand, impactive loads may be estimated using simplified energy methods. In any event, there are conflicting requirements between requirements for seismic and thermal loading. More specifically, the gap between the seismic retainer attached to the polar crane bridge and the impact plate on the support must be large enough to accommodate to some degree thermal expansions during the SSE, but not so great as to allow excess movements under seismic loading. Furthermore, use of this form of impact restraint may be further complicated by requirements that the supports undergo displacement due to growth of the containment structure due to pressure during occurrence of the design basis accident.

In the second system shown on Fig 6B, positive restraints are provided between the end of each girder and the railway support. Restraints must be applied in an externally statically determinate manner in order to accommodate thermal loading. This may be accomplished by jacking of one end of the bridge to allow free horizontal movement of that end. This restraint design suffers in its mechanical complexity, requirement for human intervention to apply the restraints prior to plant startup, and requirements for careful tolerances to be observed during fabrication. On the other hand, design forces can be simply and reliably predicted using the modal response spectra technique.

The same considerations apply to restraint of the trolley upon the crane bridge. The trolley is relatively stiff and the degree to which positive restraint is provided with the bridge significantly affects the fundamental frequency of the main girders. In this typical case, positive restraint of the trolley acted to reduce loads in the main girders by shifting the fundamental frequency off of peaks in the floor response spectra.

During periods of plant shutdown, the crane should be designed for the Operating Basis Earthquake (OBE), but not such that the crane is in a lifting operation. The probability of this event is sufficiently low that it need not be considered. When not in the parked position, seismic restraints consisting only of hooks which prevent complete liftoff of the crane wheels from the rails are required.

2.3 Response Spectra

The modal response analysis was performed using floor response spectra developed for the containment using three orthogonal directions of ground motion. In developing the floor response spectra at the polar crane support elevation, the polar crane mass was included in the global model of the containment. Due to the lack of symmetry of the containment structure, three spectra of support motion resulting from each of the three directions of ground motion were used as input to the polar crane. The SRSS method was used to combine modal response due to each input spectra on a pointwise frequency basis.

2.4 Polar Crane Design

The polar crane structural design was based principally on Crane Manufacturers Association of America (CMAA) Specification No. 70. CMAA No. 70 provides rules for proportioning and stiffener placement for the main girders. However, since seismic loading was not included in the development of CMAA No. 70, it is useful to look more closely at this code to establish any inherent limitations. Loading conditions assumed in CMAA No. 70 are essentially uniaxial. Under seismic loads, biaxial bending as well as large torsional and even axial forces are to be resisted by the main girders. Lateral and torsional loads considered by CMAA No. 70 include wind (not applicable for a nuclear containment crane) and inertial loads due to bridge motion. These represent only a small fraction of the vertical dead and live or lifted loadings.

In the CMAA code, aspect ratio requirements for the webs and flanges as well as stiffener spacing are based on consideration of three principal types of buckling, i.e., shear or diagonal buckling, longitudinal buckling, and bearing or vertical buckling. For instance, spacing of transverse stiffeners is governed by usual limits to prevent shear buckling of the webs. The formula used for transverse stiffener spacing does not include influences due to the combined shear and bending stress in the webs as a result of biaxial loading. Therefore, stiffener spacing and dimensioning was based on elastic buckling considerations performed with the aid of DIN 4114 and formulae given in Ref [3]. The approach can be expected to be conservative as any post-buckling strength of the plate girders is neglected. If the requirements of the 1969 American Institute of Steel Construction (AISC) code are used for design of the main girders it was found that stiffener requirements of the CMAA No. 70 were adequate.[4] While the AISC code makes use of post-buckling strength through introduction of "effective width" concepts, it is not necessarily adequate for this use as tests upon which the code is based are essentially static and do not adequately cover cases of combined biaxial bending, shear and torsion.

For design for the SSE, stresses were limited to 90% of the yield strength. This same factor of safety should be used for elastic buckling consideration performed using DIN 4114.

3.0 CONCLUSIONS

The design and analysis of a polar crane is usually an integrated effort involving the writing of crane design specifications and design of a crane runway support system by the plant architect/engineer and design and analysis by the crane manufacturer. Clear communication is especially needed to interface design of support systems and seismic restraint systems attached to the polar crane.

Seismic loads should be considered even in the preliminary design stages of the polar crane. Our experience suggests that seismic loading may be reduced by choice of a design which "tunes" the structure away from peaks in floor response spectra; however, the authors have not seen this approach used in practice.

LIST OF REFERENCES

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[2] "Specification for Electric Overhead Traveling Cranes," Specification No. 70, Crane Manufacturers Association of America, Pittsburgh, Pennsylvania, 1971.

[3] Moisseiff, L.S. and F. Lienhard, "Theory of Elastic Stability Applied to Structural Design," Transactions of the American Society of Civil Engineers, Vol. 106, 1941.

[4] "Manual of Steel Construction," American Institute of Steel Construction, New York, 1969.

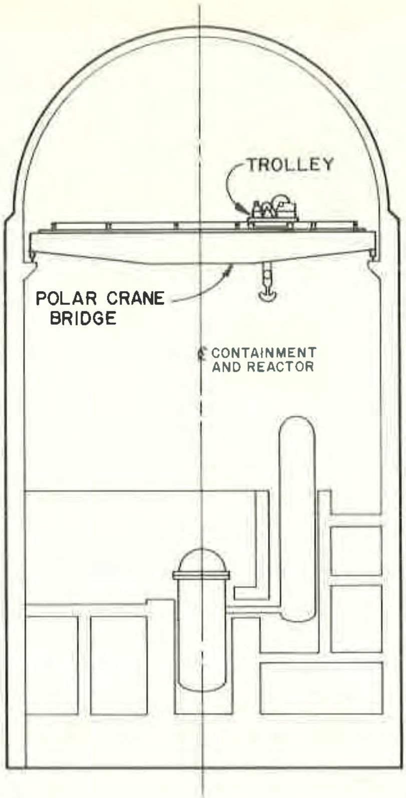

FIGURE I - TYPICAL PLANT LAYOUT SHOWING POLAR CRANE

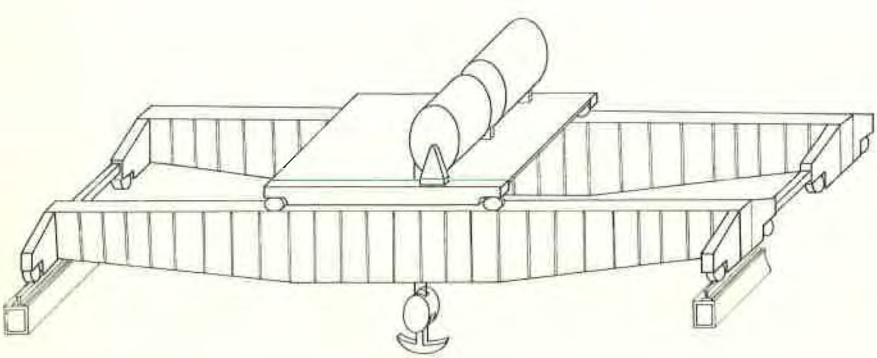

FIGURE 2 - CONCEPTUAL DWG. OF POLAR CRANE

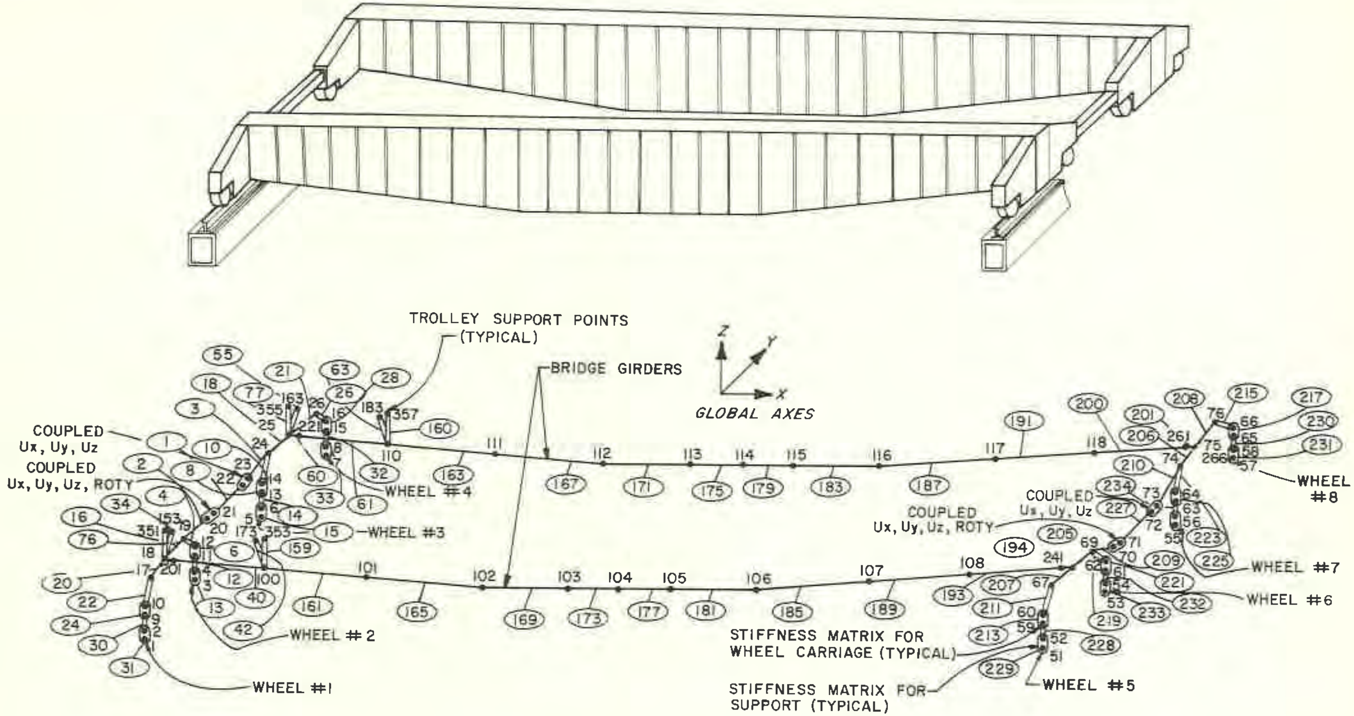

FIGURE 3 - FINITE ELEMENT MODEL OF CRANE BRIDGE

STIFFNESS MATRIX FOR CRANE RUNWAY SUPPORTS

ELEMENTS	NODES	WHEEL
31	1-2	1
13	3-4	2
15	5-6	3
33	7-8	4
229	51-52	5
233	53-54	6
235	55-56	7
231	57-58	8

WHEEL CARRIAGE STIFFNESS MATRIX ELEMENTS

ELEMENTS	NODES	WHEEL
24	9-10	1
6	11-12	2
10	13-14	3
28	15-16	4
213	59-60	5
221	61-62	6
225	63-64	7
217	65-66	8

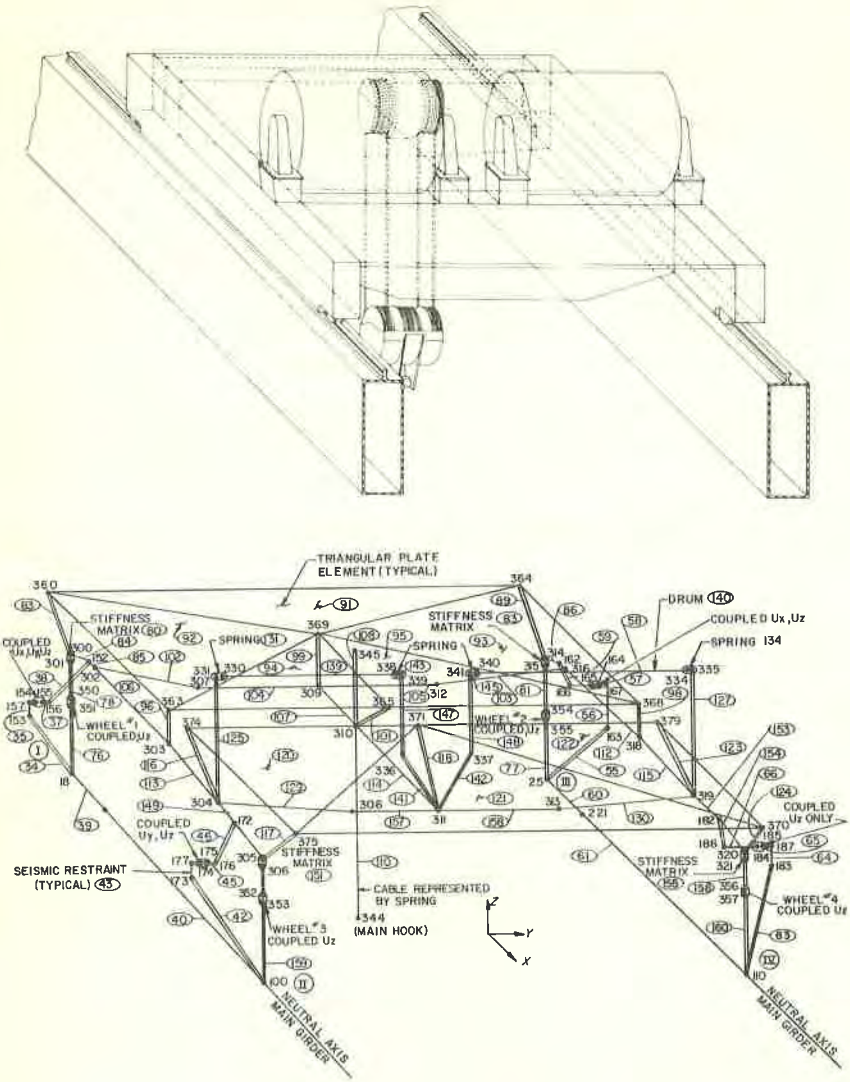

FIGURE 4 – FINITE ELEMENT MODEL TROLLEY

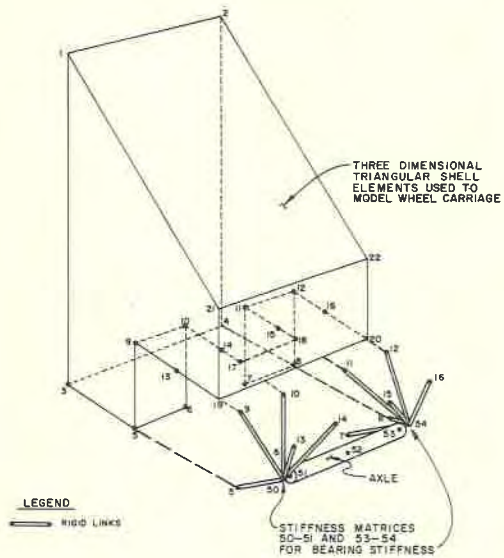

FIGURE 5

FINITE ELEMENT MODEL OF WHEEL BASE

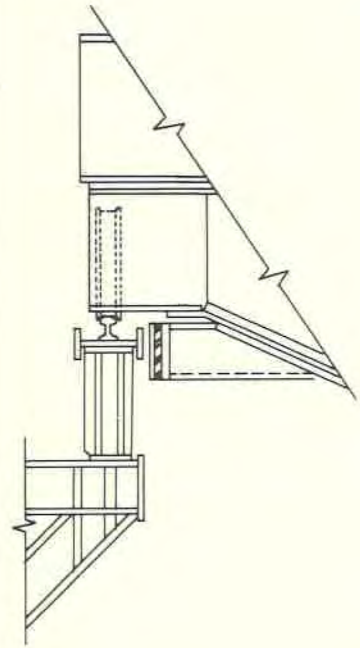

FIGURE 6A

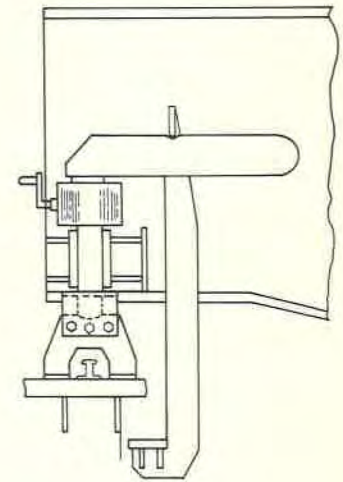

FIGURE 6B

EXAMPLES OF POLAR CRANE SEISMIC RESTRAINTS