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다목적연구용 원자로의 30/5 톤 천정크레인에 대한 지진해석에 관한 연구

Seismic Analysis of 30/5 Ton Overhead Crane for 30MWTh Korea Multipurpose Research Reactor (KMRR)

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ABSTRACT

The KMRR 4-wheel crane which has a span of 30.6m long shall be designed to maintain its structural integrity during and after seismic shocks. Horizontal and vertical FRS for OBE and SSE conditions at the crane support are used as seismic inputs ; horizontal ZPA of SSE and OBE are 0.73g and 0.5g, respectively. The material dampings used in the analysis are 4% for OBE and 7% for SSE. The crane consists of girder, saddle, main and auxiliary trolley, and accessaries. They are modeled as beam elements and lumped masses for the following 4 cases ; trolley at center of the crane with and without the rated load, trolley at end with and without the rated load.

The static analysis as well as the linear dynamic analysis including frequency and response spectrum analysis are performed for the seismic qualification of the crane using the Finite Element Method. For the simplicity of the analysis, the decoupling criteria are considered for the crane rope and the crane supporting beams. The main sections of the crane are stiffened until the calculated stresses satisfy the allowable limits. The seismic resultant loads are used to design the seismic restraints of the saddle and the trolley to protect the crane from the seismic uplifting loads. The study results have shown that the seismic design of the KMRR crane is governed by the OBE condition, not by the SSE condition. This paper briefly describes the analysis procedure used in the seismic design of the KMRR crane, and summarizes the analysis results.

1. INTRODUCTION

A 30/5 ton overhead crane is required to be installed in the Reactor Building of the 30MWTh Korea Multi-purpose Research Reactor (KMRR). It will be used for handling shielding slabs, manbridge and neutron experimental facilities, etc., during construction, normal operation and maintenance of the reactor.

The crane shall be designed to maintain its structural integrity when subjected to the Design Basis Earthquakes such as Operating Basis Earthquake (OBE) as well as Safe Shutdown Earthquake (SSE) ; the crane shall not fail under the rated load of 30 tons.

The crane consists of a box type girder, saddle, trolley saddle and trolley. The crane shall be designed and fabricated according to the CMAA specification #70 [1].

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The Floor Response Spectra (FRS) curves typically shown in Fig.1 for the horizontal OBE and SSE are given at the crane support. Horizontal ZPA for SSE and OBE are 0.73g and 0.5g, and vertical ZPA for SSE and OBE are 0.35g and 0.2g respectively.

The damping values used in the analysis are 4% for the OBE case and 7% for the SSE respectively.

The static and dynamic load combinations are summarized as follows.

Static case ; S = D + L
Seismic cases ;
OBE 1.33S = D + L + E (OBE)
SSE 1.6S = D + L + E (SSE)
where S : Combined Stresses
D : Stresses due to Dead Weight & Rated Load
L : Stresses due to Live Load
E : Earthquake Stresses

The material of the crane girder, saddle and trolley is carbon steel (ASTM A36).

2. MODELING AND ANALYSIS OF CRANE

The crane is decoupled from the rigid crane supporting beams which have a fundamental frequency much higher than 33Hz. Beam elements having 6 d.o.f. (3 translations & 3 rotations) are used for modeling the crane. The finite element computer code ADINA [2] is utilized for the analysis.

Mathematical models representing the location of trolley (at the center and the end of the girder) and with or without the rated load are used for the static, OBE and SSE analyses. The boundary conditions used in the analysis follow the requirements of the ASME NOG 4000 [3] as shown in Fig.2.

Concentrated masses are considered for the distribution panels, cables, walkways in the girder, and for the wheel assembly and the driving mechanism of the saddle, and for the main and the auxiliary driving mechanism of the trolley.

Geometrical properties of the girder, saddle and trolley are simplified as a uniform box section. Design changes are made to the crane members as shown in Fig.3 to meet the allowable stress limits.

The pendulum effect of the rated load is considered in the analysis model by decoupling the crane rope from crane for a simplified analysis, and equivalent masses which include the pendulum effect are applied at the points where the rated load is hanged. The analysis model for the trolley at center is typically shown in Fig.4.

The static analysis is carried out first to check the deflection limit and stresses of the crane, then the frequencies and mode shapes are calculated.

The SRSS method is used for the modal combination for each earthquake direction, then the spatial combination for all three directions is made to obtain the resultant forces and moments for each element.

From the calculated resultant forces, the crane equivalent stresses are calculated using the post processor [INPUT] which is written in accordance with the equivalent stress formula as follows :

Equivalent stress = (bending stresses + 3 * shear stresses)½

For the load combination, the resultant stresses for static, OBE and SSE loads are combined as described in the section 1 and compared with the code allowable limits.

The runway reaction forces at the crane saddle and at the trolley saddle are used to design the seismic restraints to prevent them from derailments of the crane supporting beams and the crane girder.

3. RESULTS & DISCUSSIONS

A design change to the crane section members is made as shown in Fig.3 due to insufficient stress margin of safety for the original design. Table 1 shows the comparison of natural frequencies between the original and the modified analysis models for the trolley at center with the rated load.

The significant frequency of the original model is 8.28 Hz and the peak accelerations of the FRS are accordingly 3.5g for OBE and 4.2g for SSE, while for the modified model is 11.1Hz and the peak acceleraitons are remarkably reduced to 1.4g for OBE and 1.8g for SSE.

Based on this result, the analyses for the modified model for various loading conditions are proceeded.

The natural frequencies for the modified design are shown in Table 2 for all cases. The cutoff frequency used in the analysis is higher than 40Hz. The significant mode shapes when the trolley at the center of the crane are shown in Fig.5.

The fundamental frequencies of the trolley at center are 2.83Hz (vertical-z), 3.4Hz (horizontal-y) and 11.1Hz (horizontal-x) with the rated load, and 3.11Hz (horizontal-y), 3.7Hz (vertical-z) and 9.8Hz (horizontal-x) without the rated load. And those of the trolley at the end are 4.97Hz (vertical-z), 5.1Hz (horizontal-y) and 12.8Hz (horizontal-x) with the rated load, and 5.11Hz (horizontal-y), 5.6Hz (vertical-z) and 12.6Hz (horizontal-x) without the rated load.

The natural frequencies when the crane is loaded are lower than those when the crane not carrying the load, and the crane frequencies for the with load case in the vertical direction are lower than those for the without load case, and vice versa in the horizontal directions.

By the way, the crane frequencies for the trolley at end is higher than those for the trolley at center in all directions. In comparison of the accelerations especically in the horizontal-y direction between trolley at center and trolley at end, the former are 0.7g for OBE and 1.0g for SSE, the latter are 2.1g for OBE and 2.5g for SSE.

The summary of the maximum calculated stresses at each section of the modified crane design is shown in Table 3. The maximum stresses are obtained at the center of girder for the static condition, and at the center of trolley main beam for the static and OBE conditions when trolley at end with the rated load, and at the trolley saddle for the static and SSE conditions when trolley at end with the rated load, respectively. All stresses are within the allowable limits.

4. CONCLUSION

The dynamic characteristics, natural frequencies and mode shapes and the seismic results of the KMRR crane are investigated for various loading conditions of the trolley positions with or without the rated load. For the simplicity of the analysis, the decoupling criteria are considered for the crane rope and the crane supporting beams.

Based on the correlation between the dynamic characteristics of crane and the input FRS, the design change is applied to avoid the peak acceleration zone of FRS. The study results show that the loading condition for the trolley at end with the rated load is severer than that for the trolley at center with the rated load and the OBE case is governing the crane design rather than the SSE case, which are due to the higher acceleraiton level for the trolley at end and the stricter allowable stress level for the OBE condition.

Therfore, a linear seismic analysis procedure for the overhead travelling crane is applied to the KMRR crane, and the structural integrity of the crane subjected to the Design Basis Earthquakes is verified. In order to minimize the conservative approach used in the analysis, a realistic dynamic analysis to include the pendulum effect of the rated load, and to improve the boundary conditions used at the trolley and saddle wheels needs to be studied further.

REFERENCES

1. CMAA Specification #70, *Specification for* Electric Overhead Traveling Crane, 1983.
2. Computer Program, ADINA and ADINA-PLOT User's Manual, 1985.
3. ANSI/ASME NOG-1, Rules for Construction of Overhead and Gantry Cranes, 1983.

Table 1. Comparison of Frequencies between Original and Modified (Trolley at Center With Load)

MODE NO.	Original		Modified	
	FREQ.	Dir.	FREQ.	Dir.
1*	.244E+01	57-Z	.283E+01	57-Z
2	.265E+01	57-Y	.340E+01	57-Y
3	.396E+01	24-Z	.414E+01	24-Z
4	.828E+01	17-X	.111E+02	2-X
5	.969E+01	38-Y	.123E+02	14-X
6	.109E+02	22-Z	.142E+02	57-Z
7	.124E+02	32-Y	.167E+02	38-Y
8	.133E+02	27-Y	.182E+02	2-X
9	.142E+02	21-Y	.193E+02	21-Y
10	.159E+02	1-X	.202E+02	38-Y
11	.162E+02	28-Z	.208E+02	1-X
12	.190E+02	20-Y	.236E+02	22-Y
13	.192E+02	32-Z	.252E+02	32-Z
14	.212E+02	31-Y	.263E+02	54-Z
15	.250E+02	28-Z	.281E+02	31-Y
16	.257E+02	14-Z	.284E+02	54-Z
17	.298E+02	39-Z	.297E+02	21-Z
18	.307E+02	39-Y	.330E+02	28-Z
19	.335E+02	26-Y	.357E+02	54-Z
20	.345E+02	39-Y	.387E+02	28-Z
21	.361E+02	22-Y	.408E+02	31-Y
22	.376E+02	40-Y	.419E+02	39-Z
23	.394E+02	26-Z	.427E+02	22-Y
24	.441E+02	40-Z	.439E+02	22-Y
25	.449E+02	17-Z	.453E+02	22-Y
26	.470E+02	24-Y	.477E+02	2-X

Table 2. Natural Frequency for Analysis Models

MODE NO.	Trolley at Center				Trolley at End			
	With Load		Without Load		With Load		Without Load	
	FREQ.	Dir.	Freq.	Dir.	Freq.	Dir.	Freq.	Dir.
1	.283E+01	57-Z	.311E+01	35-Y	.497E+01	35-Z	.511E+01	36-Y
2	.340E+01	57-Y	.370E+01	35-Z	.512E+01	36-Y	.568E+01	36-Z
3	.414E+01	24-Z	.412E+01	24-Z	.681E+01	25-Y	.693E+01	25-Y
4	.111E+02	2-X	.988E+01	17-X	.755E+01	25-Y	.788E+01	25-Z
5	.123E+02	14-X	.112E+02	14-X	.105E+02	25-Z	.126E+02	2-X
6	.142E+02	57-Z	.135E+02	32-Y	.128E+02	2-X	.135E+02	1-X
7	.167E+02	38-Y	.151E+02	27-Y	.134E+02	1-X	.160E+02	38-Y
8	.182E+02	2-X	.166E+02	21-Y	.159E+02	34-Y	.169E+02	23-Y
9	.193E+02	21-Y	.167E+02	31-Z	.169E+02	14-Z	.178E+02	33-Z
10	.202E+02	38-Y	.194E+02	1-X	.184E+02	23-Y	.197E+02	24-Y
11	.208E+02	1-X	.198E+02	21-Z	.189E+02	27-Z	.209E+02	27-Z
12	.236E+02	22-Y	.207E+02	20-Y	.201E+02	24-Y	.232E+02	1-X
13	.252E+02	32-Z	.232E+02	54-Z	.232E+02	1-X	.233E+02	54-Z
14	.263E+02	54-Z	.233E+02	31-Y	.239E+02	14-Z	.243E+02	14-Z
15	.281E+02	31-Y	.268E+02	17-Z	.266E+02	54-Z	.275E+02	54-Z
16	.284E+02	54-Z	.279E+02	54-Z	.277E+02	27-Z	.280E+02	17-Z
17	.297E+02	21-Z	.283E+02	14-Z	.281E+02	28-Y	.309E+02	39-Y
18	.330E+02	28-Z	.322E+02	28-Z	.306E+02	39-Z	.311E+02	39-Y
19	.357E+02	54-Z	.348E+02	54-Z	.309E+02	39-Y	.317E+02	22-Y
20	.387E+02	28-Z	.359E+02	39-Y	.315E+02	38-Y	.341E+02	24-Z
21	.408E+02	31-Y	.368E+02	39-Z	.336E+02	24-Z	.364E+02	54-Z
22	.419E+02	39-Z	.376E+02	22-Y	.360E+02	54-Z	.383E+02	24-Z
23	.427E+02	22-Y	.425E+02	30-Z	.379E+02	24-Z	.395E+02	2-X
24	.439E+02	22-Y	.447E+02	27-Y	.394E+02	2-X	.441E+02	24-Y
25	.453E+02	22-Y	.459E+02	52-Z	.423E+02	52-Z	.449E+02	57-Z
26	.477E+02	2-X	.479E+02	51-Y	.440E+02	24-Y	.464E+02	1-X

Table 3. Summary of Max. Calculated Stresses at Each Section

Section	Actual Stress (Pa)		Allowable Stress
Girder	Static	.8669E+08	0.49 Sy (= 121 MPa)
	Static + OBE	.1200E+09	0.6 Sy (= 149 MPa)
	Static + SSE	.1400E+09	0.9 Sy (= 223 MPa)
Saddle	Static	.5935E+08	0.49 Sy (= 121 MPa)
	Static + OBE	.1340E+09	0.6 Sy (= 149 MPa)
	Static + SSE	.1590E+09	0.9 Sy (= 223 MPa)
Trolley (Main)	Static	.7462E+08	0.49 Sy (= 121 MPa)
	Static + OBE	.1400E+09	0.6 Sy (= 149 MPa)
	Static + SSE	.1520E+09	0.9 Sy (= 223 MPa)
Trolley (Aux.)	Static	.3219E+08	0.49 Sy (= 121 MPa)
	Static + OBE	.1070E+09	0.6 Sy (= 149 MPa)
	Static + SSE	.1170E+09	0.9 Sy (= 223 MPa)
Trolley Saddle	Static	.4435E+08	0.49 Sy (= 121 MPa)
	Static + OBE	.1510E+09	0.6 Sy (= 149 MPa)
	Static + SSE	.1650E+09	0.9 Sy (= 223 MPa)

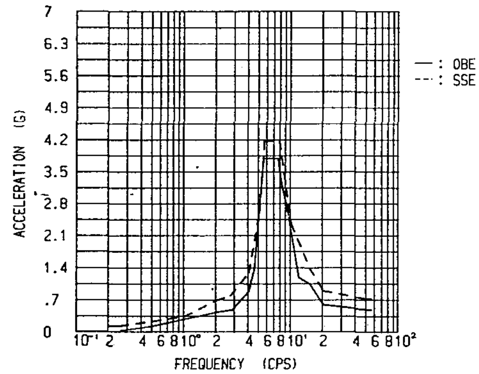
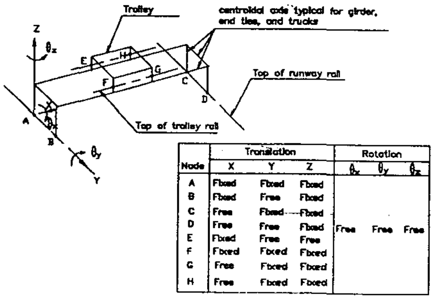


Fig. 1 Horizontal FRS for KMRR Crane, OBE and SSE



Node	Translation			Rotation		
	X	Y	Z	θ_x	θ_y	θ_z
A	Fixed	Fixed	Fixed	Free	Free	Free
B	Fixed	Free	Fixed			
C	Free	Fixed	Fixed			
D	Free	Free	Fixed			
E	Fixed	Free	Free			
F	Fixed	Fixed	Fixed			
G	Free	Fixed	Fixed			
H	Free	Fixed	Fixed			

Fig. 2 Boundary Conditions Used in Analysis

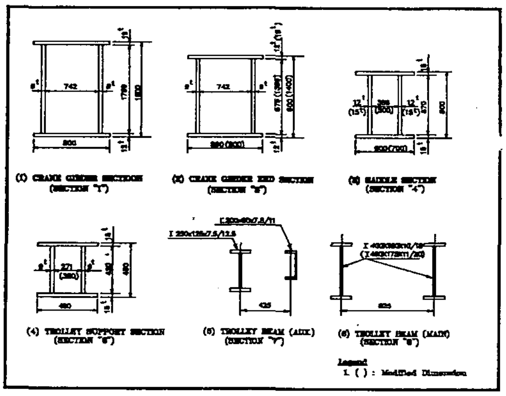


Fig. 3 Typical Geometry of Crane

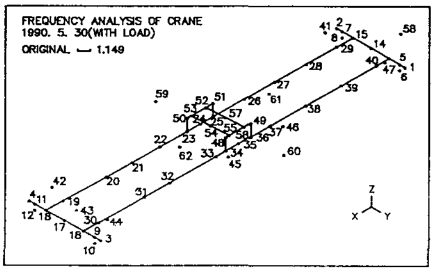


Fig. 4 Crane Analysis Model for Trolley at Center

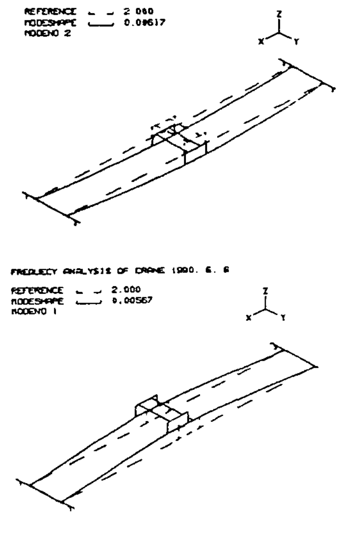


Fig. 5 Typical Mode Shape for Trolley at Center
(a) Mode 1 (Vertical Z-Dir.)
(b) Mode 2 (Horizontal Y-Dir.)