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A Preliminary Structural Design Study on High Performance Container Crane

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Abstract

After the introduction of the World Trade Organization, large scale container ships are being used as a means of transportation for international trade.
Therefore, improving the loading and unloading capability of container quays is the most economic way, considering the cost needed for the establishment or expansion of container quays.
In this paper, a new container cargo handing system that is equipped with a high performance container crane is suggested. A structural analysis on the container crane is also conducted to decide the form and size of structural member scantlings, using NASTRAN, which is a general structure analysis program.
Keywords: container crane, container handling, time analysis, structural analysis

1 Introduction

The volume of international container cargoes is increasing rapidly due to increased capability of container ships in terms of size and speed.

This requires that container handling system needs to accommodate the above trend for better economics and performance. A general type of container crane has not been changed for last 40 years, while the size of container crane has been increased to the Panamax class (the outreach range of within 44m), the Post Panamax class (the outreach range of between 44m and 48m) and the Super- Panamax class (the outreach range of over 48m).

In this paper, therefore, the time analysis is carried out to seek the most efficient container handling system with an example of Port of Incheon, Korea, where a tidal difference is about 8.5m. (CreaTech 1999; Kim et al 2004) And the basic system of high performance container crane only considered the loads of the crane itself and operating system with machinery.

2 The components of high performance container crane

Table 1 shows functions of the major components and the components of high performance container crane are shown in Figure 1.

Table 1: Functions of components

Components	Functions
Major tower	It is composed of four vertical columns supporting a horizontal boom.
Boom	It is a long horizontal beam structure and trolley, spreader and container move alongside.
Trolley	It moves on the track with combined spreader or spreader/container combination.
Hoist	It takes care of ascending or descending containers to the land or the ship by using the spreader with the hook.
Hook	It winds a hoist drum round with hard cable and is ascending or descending spreader.

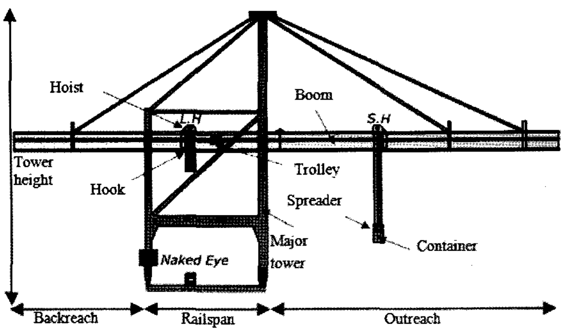


Figure 1: The components of high performance container crane

3 The principal task of high performance container crane

A container, trolley, spreader and hook are combined with or separated from to move container repetitively. Figure 2 shows the combination of major components.

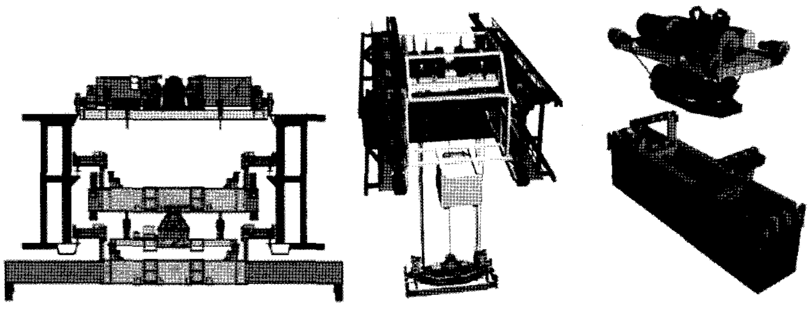


Figure 2: Container/spreader/trolley combination

3.1 Combination of major components

Trolley+Spreader

A trolley/spreader combination is a basic unit for moving. Actually, it is case of returning at the original position to pick up containers after unloading

Spreader+Hook

A container is separated from or combined with spreader, and a hook is the component which is ascending or descending this spreader from trolley to the landside or seaside

Spreader+Hook+Container

An unloading spreader/hook is combined with container and then this combination move up until a trolley position by hoist lifting a hard cable connected hook.

3.2 Procedure for container lifting

a. Coupling of roller spreader and head block with twist lock.
b. Slight ascending of coupled roller spreader and folding of rollers.
c. Lowering of coupled roller spreader and expanding of telescopic beam.
d. Lifting of coupled roller spreader with container.

3.3 Task sequence

A coupled spreader with a container is ascending automatically, see Figure 3.

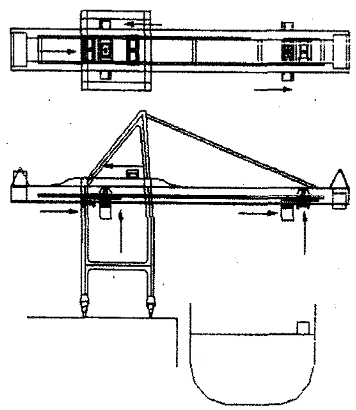


Figure 3: The joining trolley and the ready for next task

Once it is arrived under the boom, the Spreader is placed on the lower track, see Figure 4.

The separated spreader with a container is moving horizontally and the head block is moving vertically. Subsequently, an empty spreader on the middle track moves into position is connected to the head block and the coupled spreader starts to move down, see Figure 5.

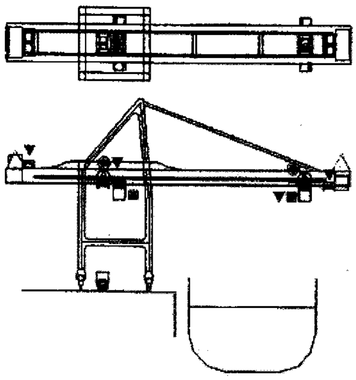


Figure 4: Before the descent of spreader and container

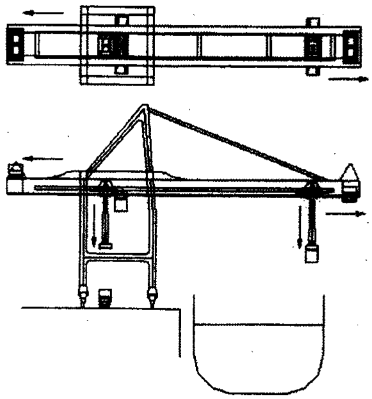


Figure 5: The descent of spreader and container

As the coupled spreader descends, the spreader arms and flippers are spreading, it has reached its stopping position, above the ground, see Figure 6.

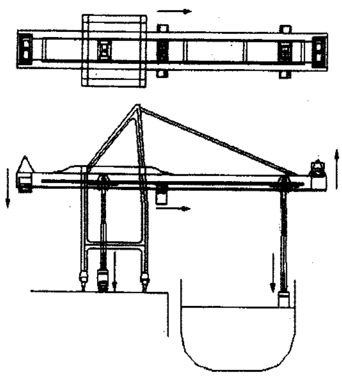


Figure 6: The joining of container and the unloading

After a soft landing on the waiting container, the twist lock is secured and the locking is confirmed. Then it starts to ascend with the container automatically. The same operation happens at the seaside hoist trolley. Once the container at the seaside is disconnected from its spreader, another spreader with a container from the landside starts to move horizontally, see Figure 7.

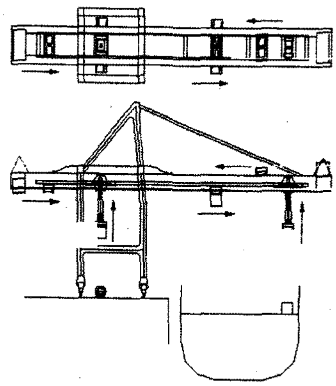


Figure 7: The ascent of spreader and container

4 Time analysis of a crane system

4.1 Time analysis of an existing container crane

Movement route

The whole sequence is shown in Figure 8 in conjunction with the following movement routes at Port of Incheon.

A~B: interval which the container crane of landside unloads or loads the container.

B~C: interval which the container moves and combines with the trolley or trolley movement only.

C~D: interval which the seaside container crane unloads or loads the container at the ship.

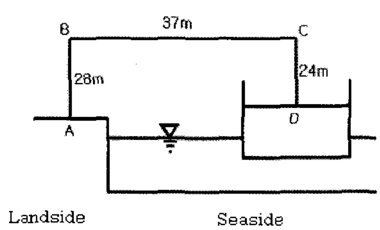


Figure 8: Movement route of an existing container crane

Time analysis of main hoist time

An ascent (V_l) or descent (V_n) speed of the spreader that is used for container shifting is 55m/min (0.92m/sec: loading) and 120m/min (2m/sec: unloading).

Table 2 shows an ascent or descent time and distance of the spreader measured by using the V_l and V_n.

Time analysis of the trolley travel

The time analysis is shown in Table 3.

Table 2: Main hoist time

Conditions			Time (sec)		Distance (m)	
			A ~ B	C ~ D	A ~ B	C ~ D
With load	Hoist	Accelerate	1.0	1.0	0.5	0.5
		Running	29.7	25.3	27.2	23.2
		Decelerate	0.7	0.7	0.3	0.3
		Total	31.4	27.0	28.0	24.0
	Lower	Accelerate	0.7	0.7	0.3	0.3
		Running	29.7	25.3	27.2	23.2
		Decelerate	1.0	1.0	0.5	0.5
		Total	31.4	27.0	28.0	24.0
Without load	Hoist	Accelerate	4.0	4.0	4.0	4.0
		Running	11.0	9.0	22.0	18.0
		Decelerate	2.0	2.0	2.0	2.0
		Total	17.0	15.0	28.0	24.0
	Lower	Accelerate	4.0	4.0	4.0	4.0
		Running	11.0	9.0	22.0	18.0
		Decelerate	2.0	2.0	2.0	2.0
		Total	17.0	15.0	28.0	24.0

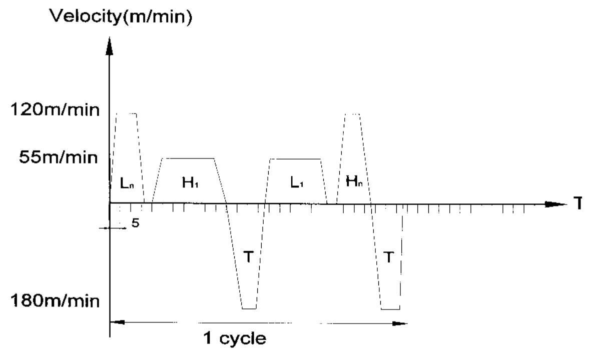
Table 3: Trolley travel time

Condition		Time (sec)	Distance (m)
With load	Accelerate	5.0	7.5
	Running	7.3	22.0
	Decelerate	5.0	7.5
	Total	17.3	37.0
Without load	Accelerate	5.0	7.5
	Running	7.3	22.0
	Decelerate	5.0	7.5
	Total	17.3	37.0

Time analysis diagram

As shown in Figure 9, which is taken from Tables 2~3, one cycle operation time of existing container crane consists of the following time-related factors,

$$\begin{aligned}\text{1 cycle time} &= L_n+L_l+H_n+H_l+T_l+T_u+2T \\ &= 7+27+15+31.4+5+5+34.6 \\ &=135 \text{ (sec)}\end{aligned}$$



L_n: descent time without load
L_l: descent time with load
H_n: ascent time without load
H_l: ascent time with load
T_u: unloading time
T_l: loading time
T: trolley travel time

Figure 9: Time analysis diagram of an existing container crane

4.2 Time analysis of the high performance container crane

Overview

A primary difference between high performance container crane and existing container crane is enhanced performance: the former is three times faster than the latter. An existing container crane system repeats the same task that returns to the original location after loading one container, while the high performance container crane can load and unload containers simultaneously by using several trolleys

Time analysis diagram

An ascent (V_l) or descent (V_n) speed of the spreader used for container shifting is 80m/min (1.3m/sec: loading) and 170m/min (2.8m/sec: unloading).

Figure 10 shows task route of the high performance container crane by using the V_l and V_n for time analysis.

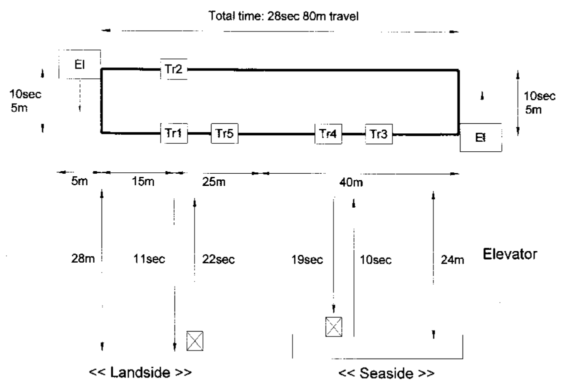
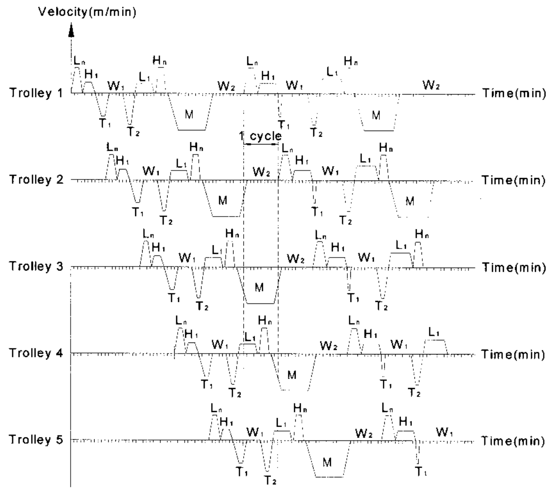


Figure 10: Task route of the high performance container crane



L_n: descent time without load
L_l: descent time with load
H_n: ascent time without load
H_l: ascent time with load

T_1: trolley travel time up to waiting position
T_2: trolley travel time up to loading position
M: trolley travel time of horizontal plus vertical
W_1: waiting time for loading of the preceding trolley
W_2: waiting time for unloading of the preceding trolley

Figure 11: Time analysis diagram of the high performance container crane

As shown in Figure 11 obtained from Figure 10, one cycle time of the high performance crane system consists of the following time-related factors,

$$\begin{aligned} \text{1 cycle time} &= T_l+L_n+H_l+\text{loading time} \\ &= 2+11+22+3 \\ &= 38(\text{sec}) \end{aligned}$$

That is, one cycle time of the high performance container crane is 38 seconds while that of existing container crane is 135 seconds; the former is three times faster than the latter.

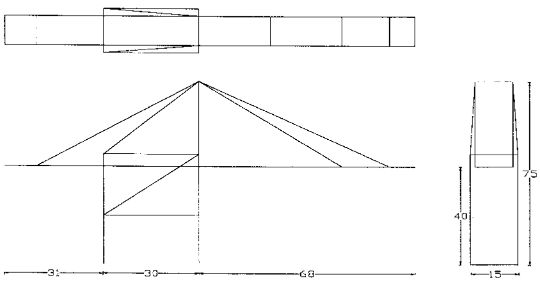
5 Preliminary structural design of the high performance container crane

5.1 Outline of structural design

In this study, to obtain the basic design system of high performance container crane, the loads of the crane itself and operating system with machinery including containers are only considered. More detailed analysis and design with additional dynamic loads can be carried out when the operating conditions are known. (Kim 2005, Kim et al 1999). The basic shape of the crane system for structural analysis is shown in Figure 12.

As shown in Figure 13, the types of structural members of the crane system are classified into 18. The member types are shown in Table 4.

The section properties of structural members are shown in Table 5.



Backreach:31 Railspan:30 Outreach:68
Railwidth:15 Height under spreader:40
Tower height:75 (Unit: m)

Figure 12: Basic shape and major scantlings of the crane system

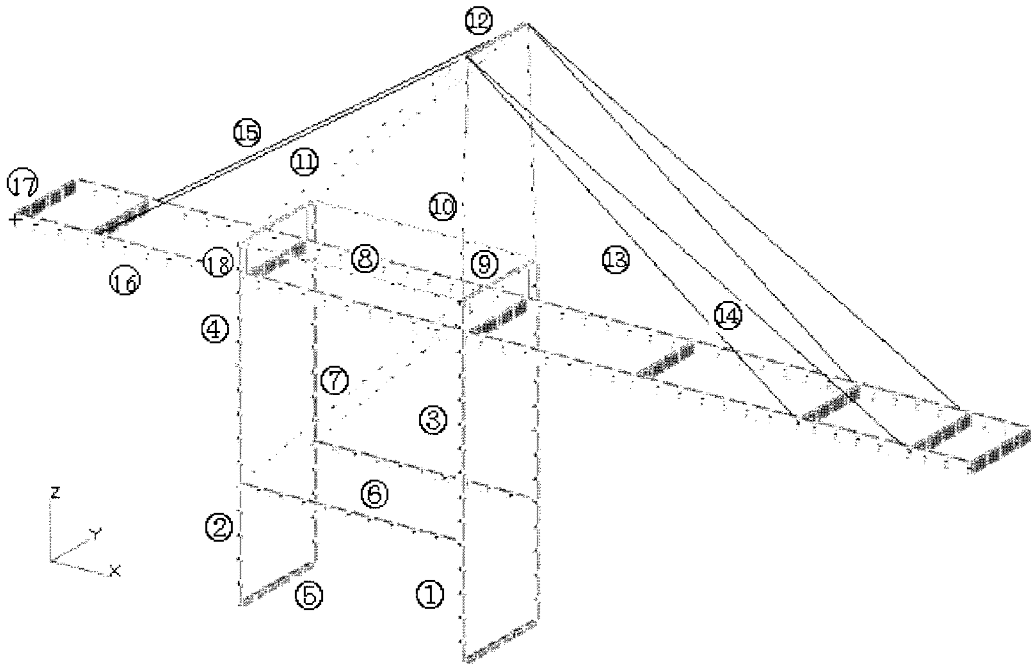


Figure 13: Structural analysis model

Table 4: Member types

Member Types	Member no.
BEAM	1-12
ROD	13-15
BEAM	16-18

5.2 Applied loads and boundary conditions

The maximum applied load to the high performance container crane is 60 tons with 20 or 40 ft container. The weights of the crane members are shown in Table 6 and three critical load conditions are considered that the displacement about x and y-axis is a free condition and it of z-axis is a fixed condition at the lowest 4 points of crane like the actual load condition, see Figures 14~16.

Table 5: Section properties of members

No.	Section Size (cm)	Section properties (cm^2, cm^4)					
		A_x	A_y	A_z	I_x	I_y	I_z
1	100 x 100 x 2	800	364	364	2.0×10^6	1.333×10^6	1.333×10^6
2	100 x 80 x 2	720	291	364	1.422×10^6	1.133×10^6	8.1 x 105
3	100 x 100 x 2	800	364	364	2.0×10^6	1.333×10^6	1.333×10^6
4	100 x 80 x 2	720	291	364	1.422×10^6	1.133×10^6	8.1×10^5
5	100 x 80 x 2	720	291	364	1.422×10^6	1.133×10^6	8.1×10^5
6	100 x 80 x 2	720	291	364	1.422×10^6	1.133×10^6	8.1×10^5
7	30 x 30 x 2	240	109	109	5.4×10^4	3.6×10^4	3.6×10^4
8	50 x 50 x 2	400	182	182	2.5×10^5	1.667×10^5	1.667×10^5
9	50 x 50 x 2	400	182	182	2.5×10^5	1.667×10^5	1.667×10^5
10	50 x 50 x 2	400	182	182	2.5×10^5	1.667×10^5	1.667×10^5
11	50 x 50 x 2	400	182	182	2.5×10^5	1.667×10^5	1.667×10^5
12	50 x 50 x 2	400	182	182	2.5×10^5	1.667×10^5	1.667×10^5
13	30 x 4	120					
14	30 x 4	120					
15	30 x 4	120					
16	100 x 200 x 2	1200	727	364	5.333×10^6	2.333×10^6	6.667×10^6
17	50 x 200 x 2	1000	727	182	1.6×10^6	5.417 x 105	4.667×10^6
18	50 x 50 x 2	400	182	182	2.5×10^5	1.667 x 105	1.667×10^5

Table 6: Weights of the crane members

Member no.	Member length (cm)	Weight per unit length (kg/cm)	Member weight (ton)
1	3,000	6.28	18.84
2	3,000	5.652	16.96
3	6,000	6.28	37.68
4	6,000	5.652	33.91
5	3,000	5.652	16.96
6	6,000	5.652	33.91
7	8,484	1.884	15.98
8	6,000	3.14	18.84
9	12,000	3.14	37.68
10	6,000	3.14	18.84
11	8,484	3.14	26.64
12	1,200	3.14	3.77
13	11,400	0.942	10.74
14	13,892	0.942	13.09
15	12,370	0.942	11.65
16	25,800	9.42	243.04
17	2,400	7.85	18.84
18	2,000	3.14	6.28

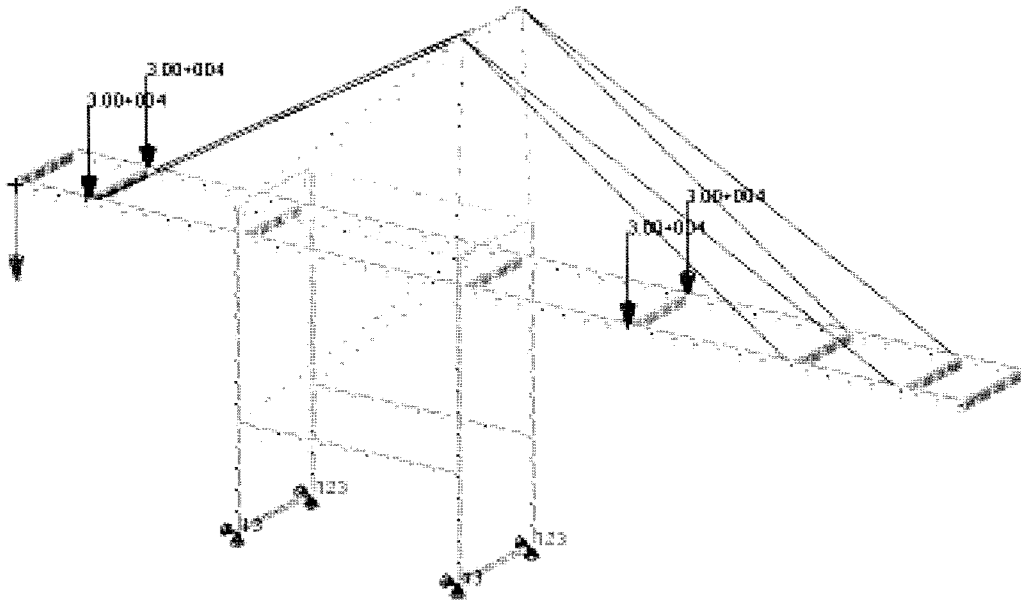


Figure 14: Load case 1

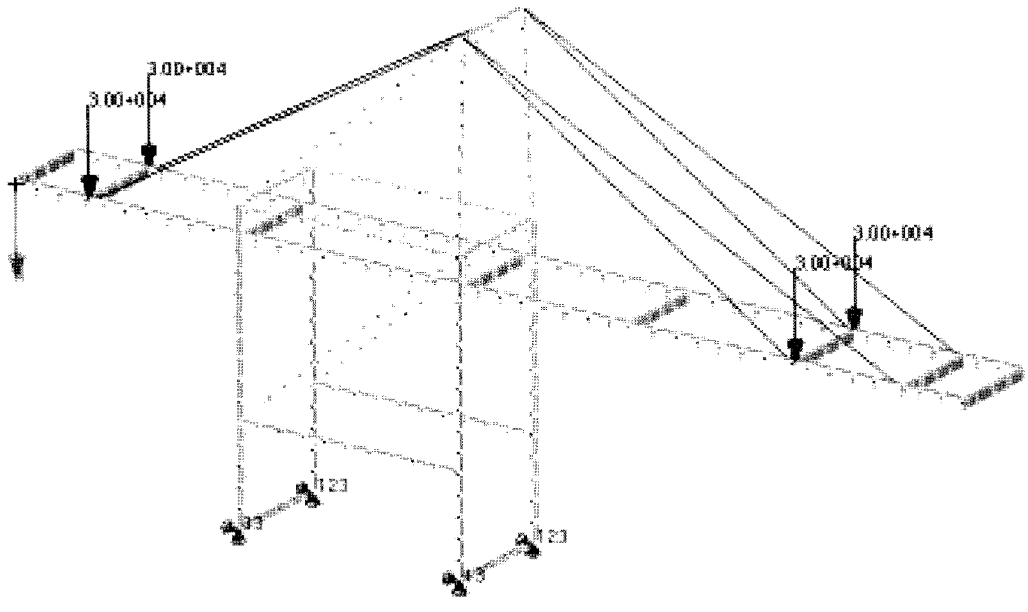


Figure 15: Load case 2

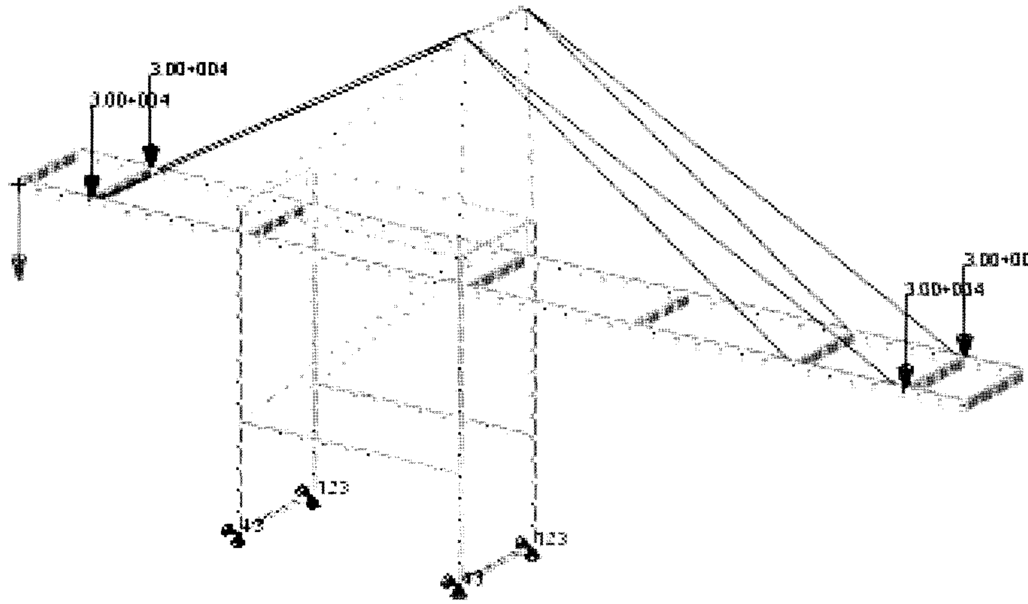


Figure 16: Load case 3

5.3 The results and discussions of structural analyses

The analyses are carried out with NASTRAN and PATRAN to examine the safety and to obtain appropriate structural member scantlings of high performance container crane.

Each element is used beam and rod for analysis, see Figure 13 and Table 4.

Deflection shapes are shown in Figures. 17~19 for each load case.

The maximum deflection on the crane boom member is 19cm, which leads to 0.16° inclination of boom. These values are not significant to horizontal operation of trolley.

The stress distributions are shown in Figures. 20~22 and Table 7 for each load case.

Higher stress values are 1,058 kg/cm² at bracing member, and 1,699 kg/cm² at vertical member of crane leg.

When the mild steel (SS41) with allowable stress of 1,800 kg/cm² is used for crane structure, it is, therefore, considered safe.

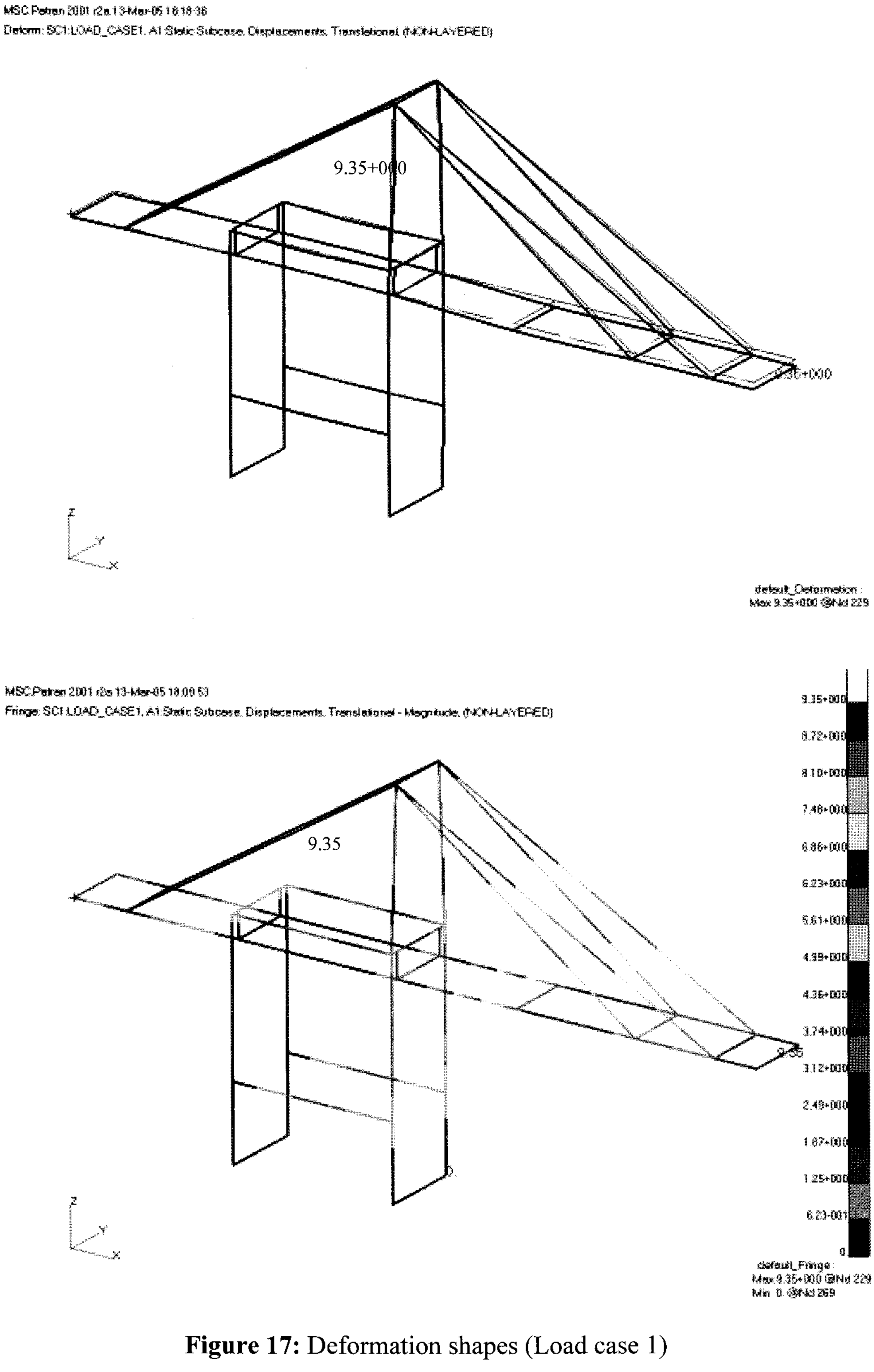
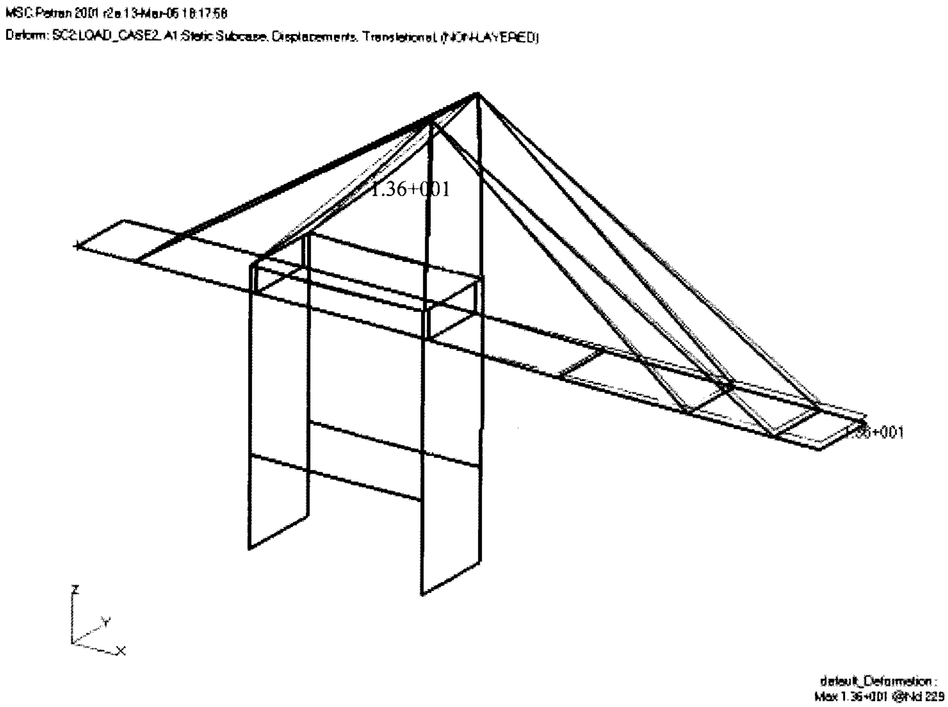


Figure 17: Deformation shapes (Load case 1)



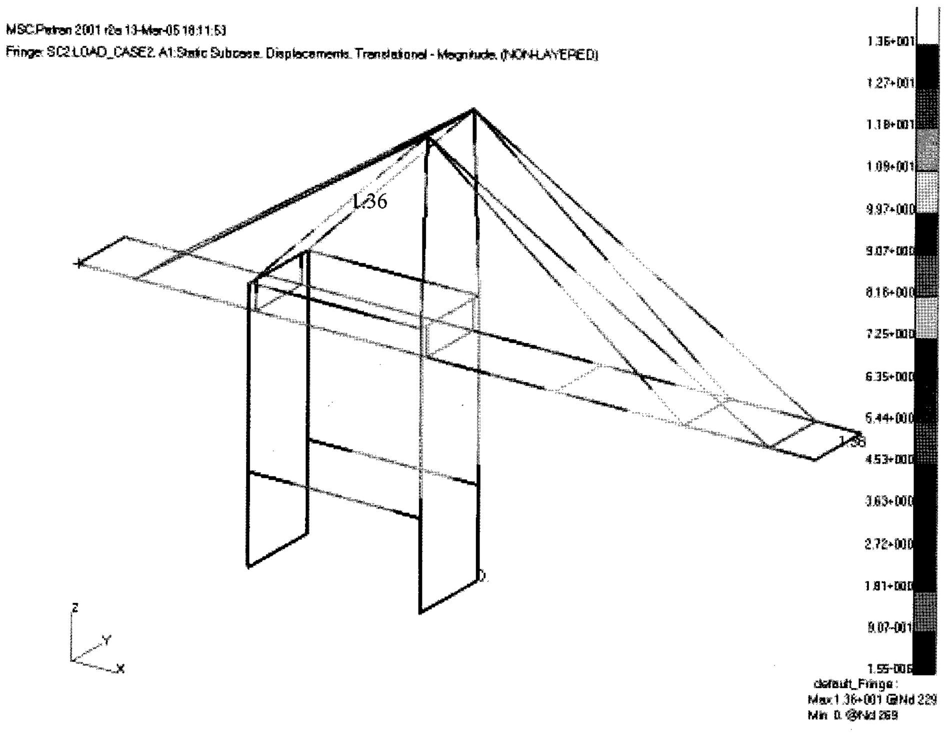
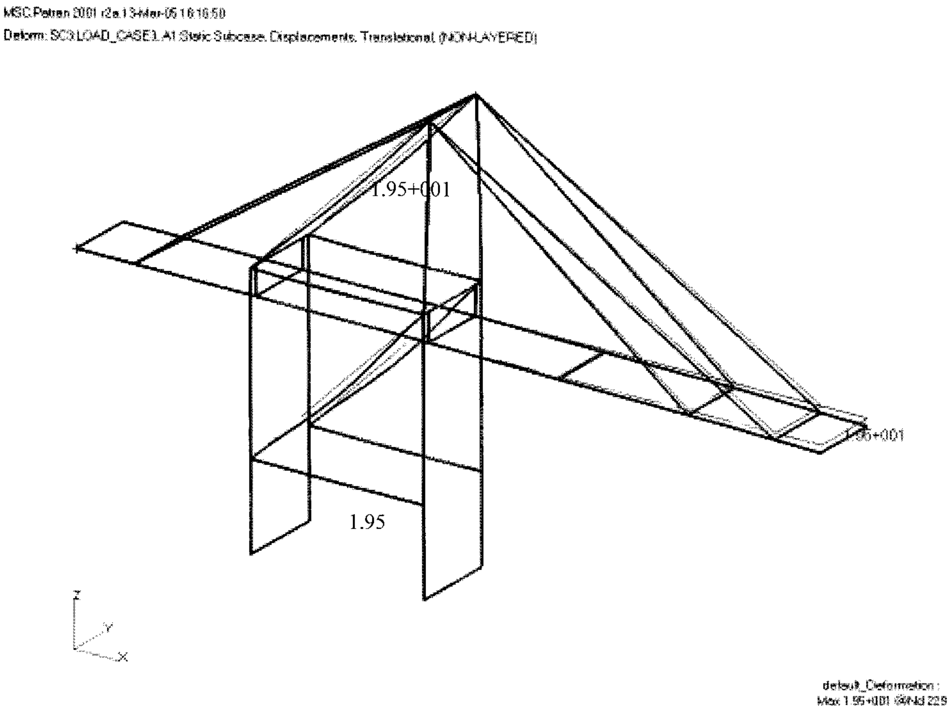


Figure 18: Deformation shapes (Load case 2)



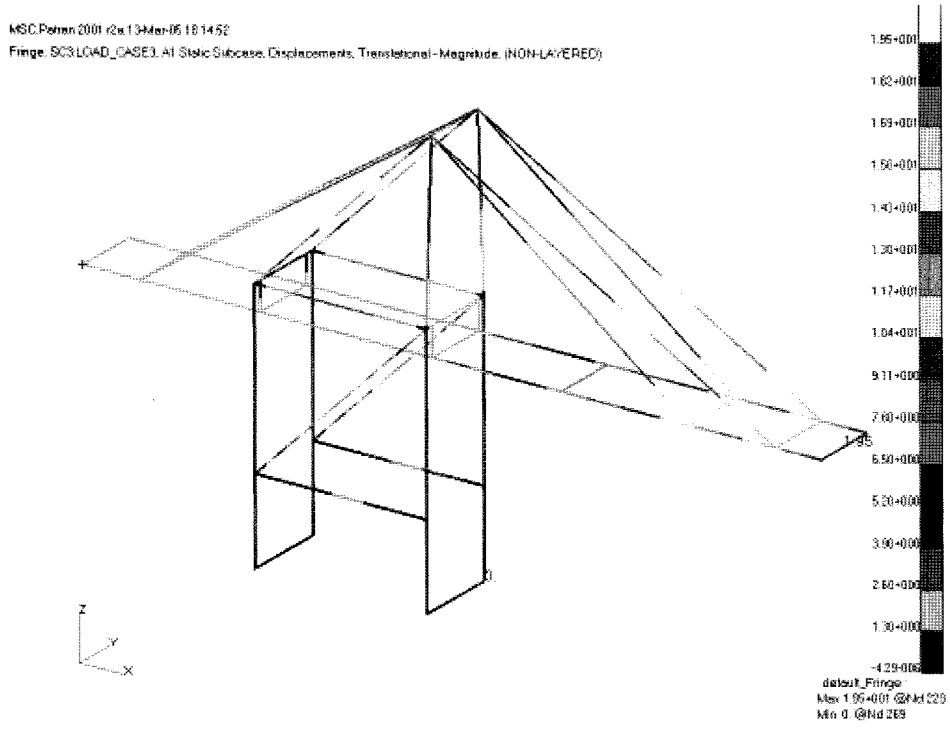
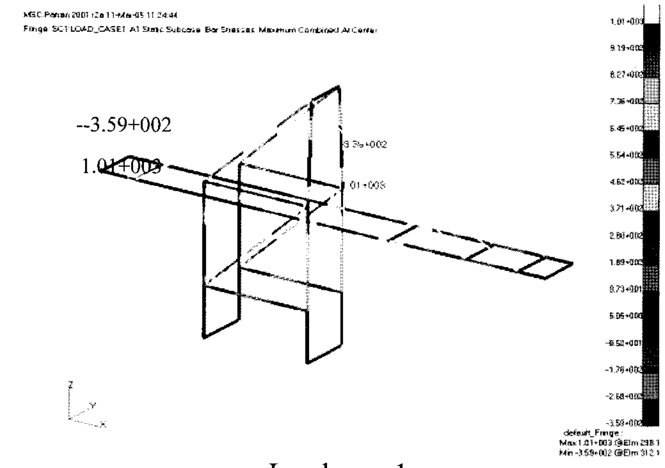
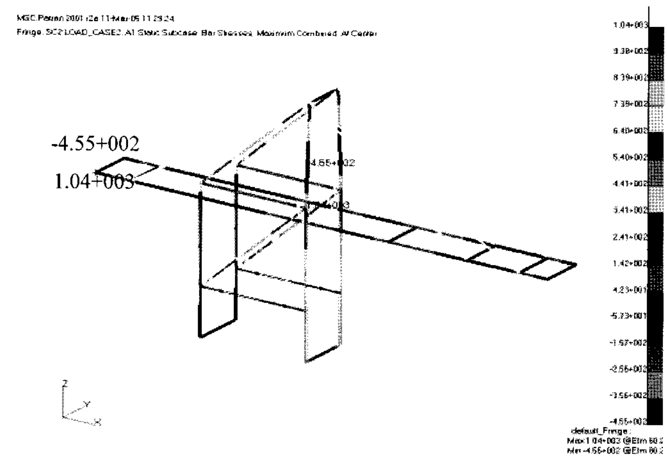


Figure 19: Deformation shapes (Load case 3)



Load case 1



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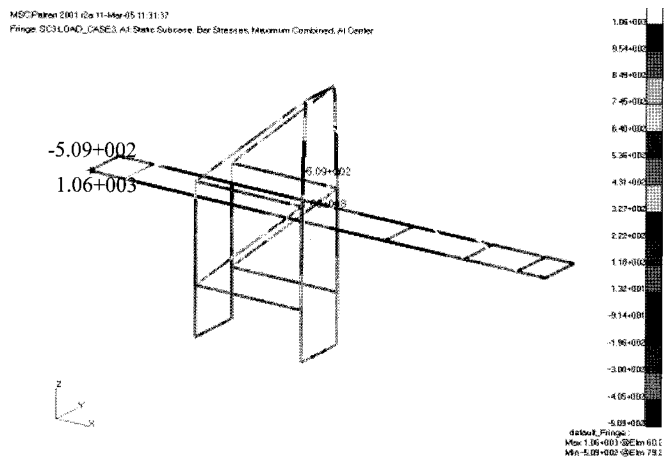
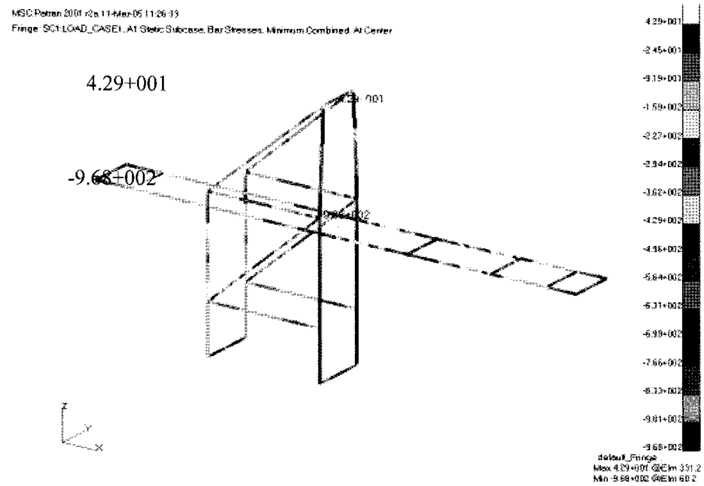
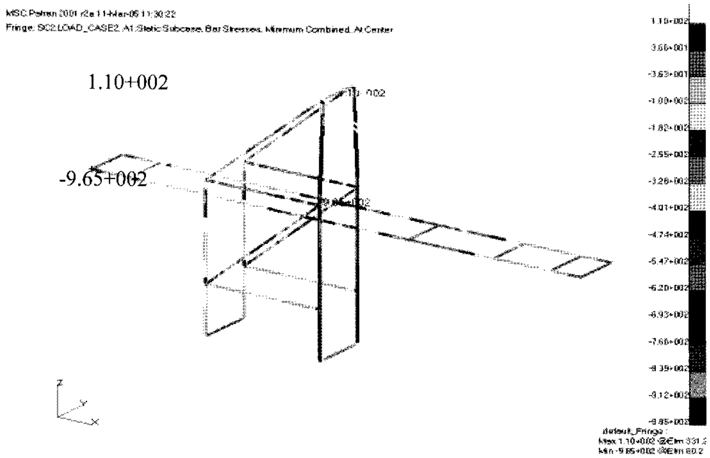


Load case3

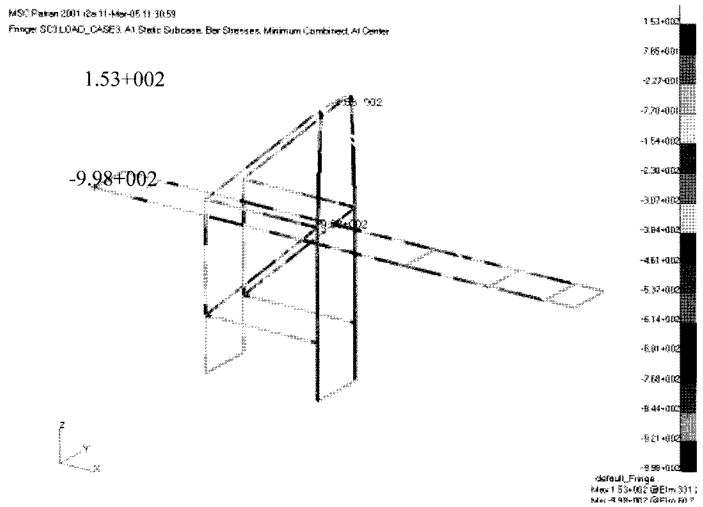
Figure 20: Contour of maximum combined stress



Load case 1

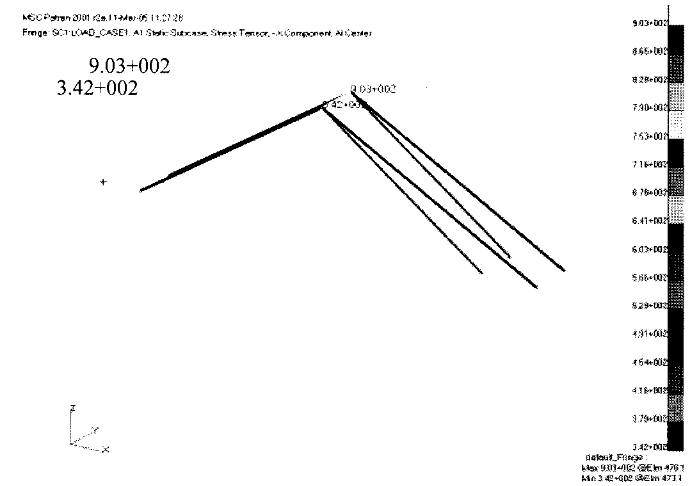


Load case 2

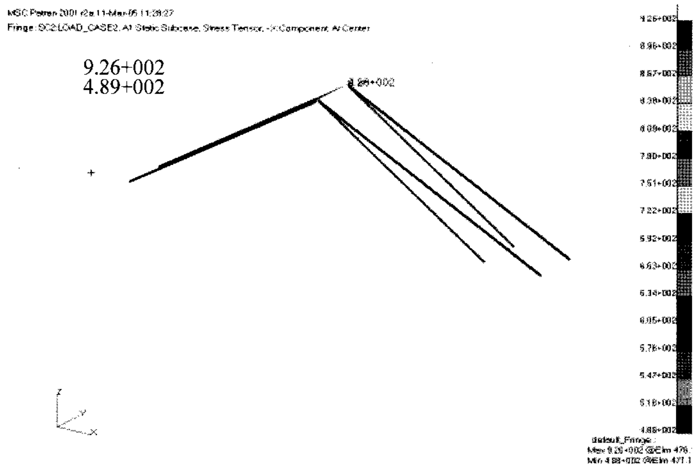


Load case 3

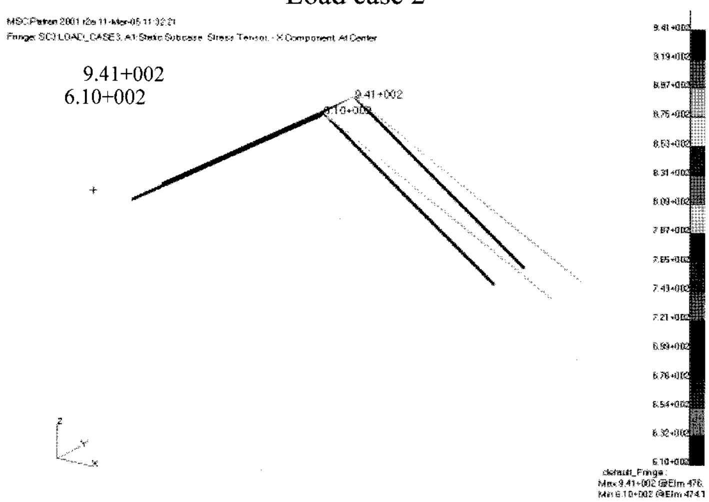
Figure 21: Contour of minimum combined stress



Load case 1



Load case 2



Load case 3

Figure 22: Contour of axial stress

6 Conclusions

In this paper, the time analysis is carried out to find the most efficient container handling system with the example of Port of Incheon, Korea, where the tidal difference is about 8.5m.

It is found that the cargo handling capability of new crane system can reach 3 times of those of conventional crane system.

Then, structural analyses are carried out to find the optimum structural system of this high performance container crane system.

Table 7: Stress distributions of crane members (unit: kg/cm²)

Seg. Nos	Ele. Nos	L.C	σ_{max}	σ_{min}
①	1	1	-314	-466
		2	-353	-464
		3	-376	-479
	5	1	-284	-458
		2	-324	-478
		3	-344	-493
②	6	1	35	-162
		2	72	-135
		3	95	-116
	10	1	-26	-118
		2	5	-84
		3	26	-66
③	11	1	-264	-451
		2	-313	-460
		3	-337	-474
	20	1	-83	-590
		2	192	-539
		3	-214	-555
④	21	1	317	-368
		2	386	-376
		3	431	-379
	30	1	131	-225
		2	175	-210
		3	210	-200
⑤	31	1	95	-91
		2	75	-73
		3	73	-70
	33	1	13	-9
		2	10	-7
		3	18	-16
⑥	37	1	70	-70
		2	207	-208
		3	220	-223
	46	1	224	-224
		2	220	-221
		3	218	-221

Seg. Nos	Ele. Nos	L.C	σ_{max}	σ_{min}
⑦	47	1	947	-949
		2	958	-948
		3	965	-948
	60	1	1009	-968
		2	1037	-984
		3	1058	-997
⑧	61	1	269	-304
		2	258	-357
		3	251	-391
	70	1	470	-775
		2	566	-666
		3	628	-768
⑨	77	1	390	-395
		2	481	-488
		3	534	-543
	86	1	156	-186
		2	199	-230
		3	228	-259
⑩	87	1	-143	-775
		2	-273	-829
		3	-338	-861
	86	1	-21	-855
		2	-122	-938
		3	-173	-984
⑪	87	1	607	-521
		2	680	-450
		3	727	-403
	100	1	453	-323
		2	540	-265
		3	595	-228
⑫	101	1	91	-134
		2	85	-129
		3	79	-128
	102	1	-77	-42
		2	-5	-41
		3	-9	-39

Seg. Nos	Ele. Nos	L.C	σ_{max}	σ_{min}
⑯	166	1	0	0
		2	0	0
		3	0	0
	169	1	70	-220
		2	68	-223
		3	67	-225
	176	1	-15	-153
		2	-63	-122
		3	-5	-191
	186	1	476	-654
		2	321	-536
		3	238	-476
	194	1	474	-652
		2	105	-320
		3	4	-243
	201	1	220	-280
		2	1	-66
		3	225	-366
	206	1	103	-103
		2	103	-103
		3	104	-104
	208	1	0	0
		2	0	0
		3	0	0
⑰	213	1	36	-37
		2	40	-34
		3	45	-36
	223	1	22	-21
		2	22	-22
		3	27	-22
⑱	477	1	1009	-915
		2	1425	-1341
		3	1699	-1624
	480	1	1327	-947
		2	1409	-1100
		3	1526	-1237

Seg. Nos	Ele. Nos	L.C	σ_{axis}
⑬	472	1	737
		2	807
		3	601
⑭	471	1	341
		2	488
		3	805
⑮	475	1	902
		2	925
		3	941

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