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The body can be viewed from the next page.

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1 Introduction

Kawasaki Steel has constructed a warehouse for storing steel products such as coils and sheets. It is a part of the company's rationalization program for product transporting, handling and storage system at Chiba works.[1-3]

Photo 1 shows a general view of the warehouse, which consists of a high-rise rack type portion and a lower ordinary portion. The rack type is the largest of its type, 10-tier and 28.4 m high, and stores heavy steel products up to 11.4 t.

This report describes a seismic design of the rack structure and some pre-fabrication methods used at construction site.

2 Outline of the Warehouse

An outline of warehouse is shown in **Table 1**, with a plan and sectional view in **Fig. 1**. The rack structure was made by structural steel. Frameworks have rahmen structure in one direction and braced structure in the other. The foundation is made by reinforced concrete structure supported by steel pipe piles. The soil around the warehouse was stabilized by slag compaction piles.

The color-coated stainless steel, "Riverlight Color" produced by Kawasaki Steel, was used for metal wall works.

3 Structural Design of Rack Structure

3.1 Setting of Live Load on Rack Structure

The rack structure is different from usual buildings in the following points:

(1) Stored products' weight (hereinafter called live load) is larger than the dead weight of the structure.

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Photo 1 General view of warehouse

Table 1 Outline of warehouse

Item \ Type	Rack type	Ordinary type
1. Area	4 333 m²	7 435 m²
2. Height	28.4 m	15.9 m
3. Storage capacity	32 000 t	9 000 t
4. Storage system	Rack	Floor
5. Handling equipment	6-stacker cranes	2-over head cranes
6. Structure	Steel	Steel
· Steel amount	3 570 t	1 070 t
7. Foundation	Steel pipe piles	Steel pipe piles
· Number of piles	266 sets	333 sets
· Pile length	48 m	48 m or 32 m

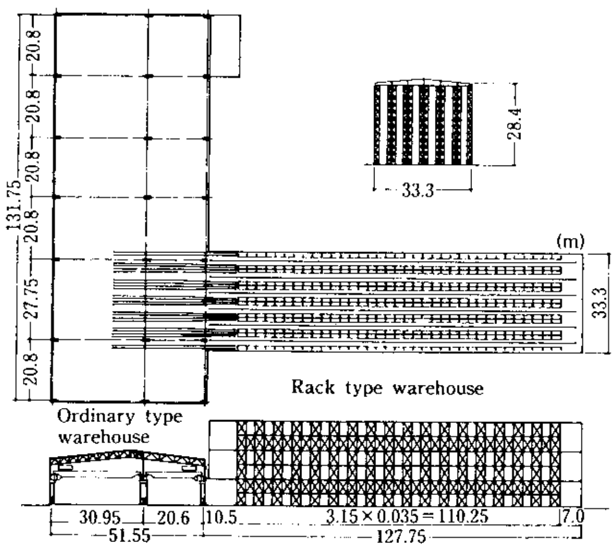

Fig. 1 Plan and sectional view of the warehouse

(2) The unit weight of the products has a large fluctuation.

As it is evidently an over-design to use maximum weight of products for every rack in designing rack structure, design load for the rack was set up so that the probability in which an actual load exceeds design load due to the changes of storaged products amount was less than a value; 1% at the usual time, 10% at the time of earthquake.

A live load for the rack design at the usual time and the time of earthquake is shown characteristically in **Fig. 2**. This shows the distribution of mean product weight per rack as the normal distribution caused by changes of stock in the warehouse. It also shows the live load set up for the rack design.

The conditions for setting up live load are as follows:

(1) Vertical load for pallet supports is 15.0 t, comprising a sum of products' maximum weight (12.0 t), pallet's weight (0.5 t), and 20% of impact loads at the time of

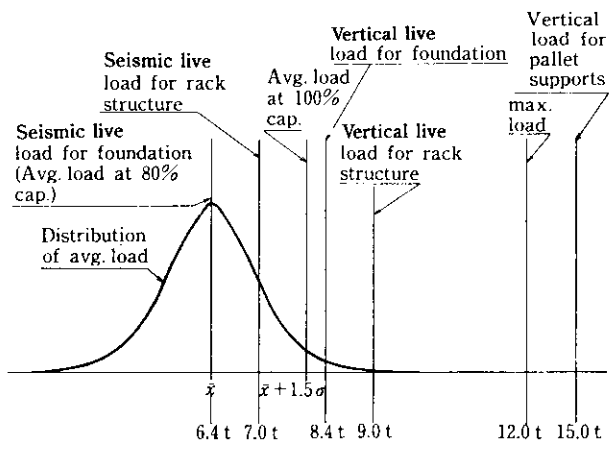

Fig. 2 Imposed load for rack structure design

loading on the rack (2.5 t).

(2) Vertical live loads imposed constantly on rack structure and foundation piles were 9.0 t and 8.4 t per rack, respectively. Those were obtained as follows. Probabilities of actual loads exceeding the design loads are less than 1%. The probabilities are got by distributions of products' mean weight of 10 samples for rack and 60 samples for piles, respectively.

(3) Live load during earthquakes for the rack structures is set up according to a probability of danger which is less than 10%, and is 7.0 t per a rack.

(4) Live load for foundation piles during earthquakes is 6.4 t per a rack, when an average load is assumed to be at 80% capacity of warehouse.

3.2 Seismic Analysis

3.2.1 Seismic response analysis

The seismic design was carried out according to the Building Standard Law of Japan.[4] But the rack structure is different from ordinary buildings in the peculiarity of no floor slabs dividing stories. Further, the rack structure has been designed by elastic seismic response analysis.

There are the following factors that influence the seismic response:

(1) Periodic characteristics of seismic waves,

(2) Distribution of stored steel products (distributions of mass),

(3) Damping characteristics.

Items (1) and (2) were adopted as analytical parameters; the seismic waves used were El Centro (1940, NS), Taft (1952, EW), and Chiba (1980, EW) with their maximum ground accelarations normalized into 200 gals, and the distribution of stored products are assumed to be in three cases; uniform distribution, biased to lower part, and biased to upper part. The damping factor is uniformly set at 2%. The calculated response tier shear force of rack structures are shown in **Fig. 3**.

The reappearance period of 200-gal earthquake is estimated to be 40~50 years in Tokyo and Chiba area. The rack structure has enough anti-earthquake capacity as the ultimate strength is much larger than the responce.

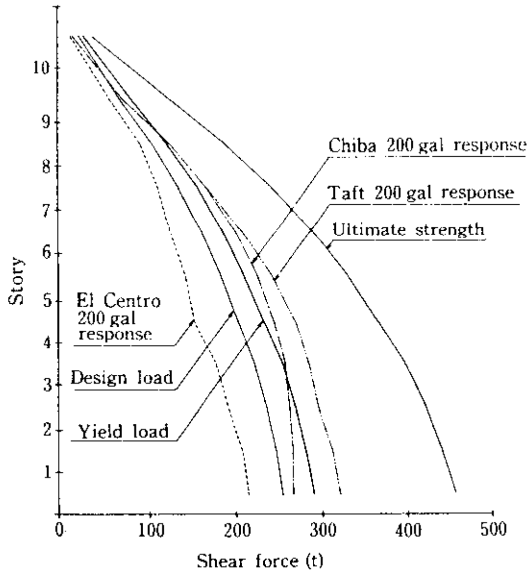

Fig. 3 Calculated story shear force

3.2.2 Vibration testing

Since the rack structure is high-rise and stores only heavy weight products supported on pallets, it is possible that stored products slide and fall down in a big earthquake. On the other hand, there is a report[5] describing that effective mass reduces during vibration if live loads are larger than the dead weight of the structure.

This test was carried out for an investigation of safety of the rack during earthquakes, and consists of two parts; one for observations of steel coils' behaviors (series 1), the other for measurements of response shear forces of the rack columns (series 2) during earthquakes.

Flow diagrams of the test is shown in **Fig. 4**. The steel

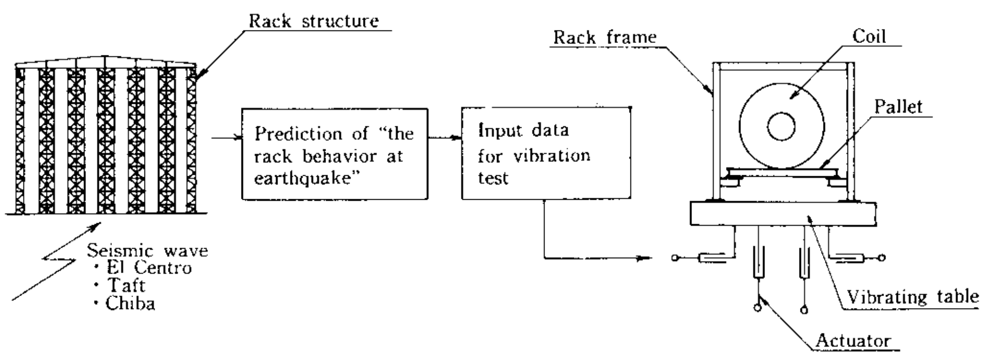

Fig. 4 Flow diagram of vibration test

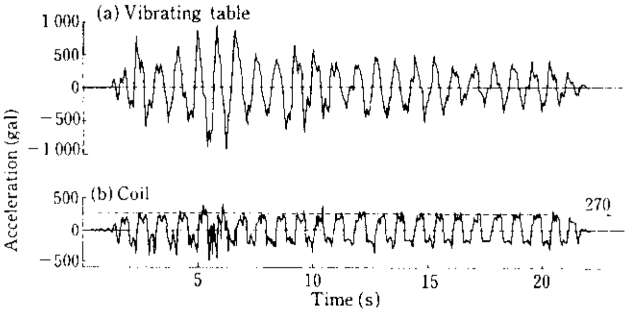

Fig. 5 Time history at vibration test (using E1 Centro response)

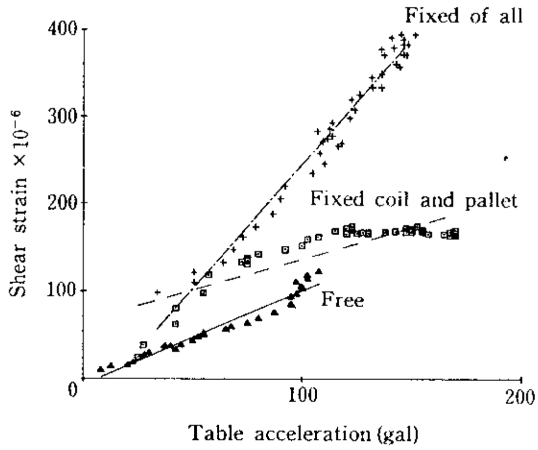

Fig. 6 Reduction of shear strain due to sliding of coil and pallet

coil specimens were vibrated both horizontally and vertically in accordance with the response waves of the rack structure calculated by the seismic responce analysis described in the previous clause.

Figure 5 shows an example of the test result. It is the time history of accelarations of the vibrating table and the coil at vibration test using E1 Centro response, when maximum ground accelaration is normalized into 200 gals. The accelaration of the coil does not exceed 270 gals in spite of the maximum of the vibrating table is 938 gals. It is almost the same in every case using other seismic waves. That is considered due to the sliding of both pallets and coils. The mean of the maximum accelaration of the coils is 260 gals.

The results of the observation of the coils' behavior show the friction factor between coils and pallets is so small that there is little probability for coils to fall down at earthquakes.

The results of the revolutional analysis between shear strains of the columns and the table accelarations are shown in **Fig. 6**. The shear strains reduce as fixity between coil, pallet and rack structure becomes small.

As the reduction of the response shear force of columns due to the sliding of coil and pallet is not considered in the design of the rack structure, the rack structure is considered to have more capacity to bear an earthquake attack than shown in Fig. 3.

4 Site Construction Works

The special features of the rack structures in construction works are as follows:

(1) The rack structure is a multiplication of the same structure.

(2) The dimensional allowance of rack structures is set up very severely.

Therefore, the pre-fabricated construction methods shown in **Fig. 7** were adopted to make quality control easy and shorten the construction period. An outline of new construction system is as follows.

(1) Steel structures of racks were assembled on the ground as much as possible **(Fig. 8)**

(2) Pre-fabricated metal wall panels including windows were used in wall works **(Photo 2)**

(3) Movable stages on crane run way girders were used in roof works.

The items (2) and (3) brought about safe operations and reductions in scaffolding works around walls and roofs, which would otherwise have been necessary in ordinary methods.

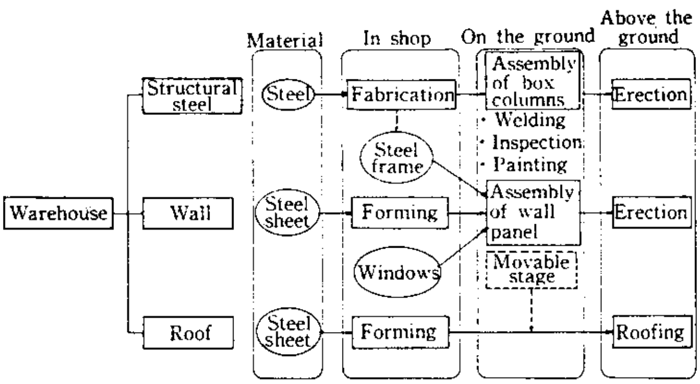

Fig. 7 Warehouse constructing system

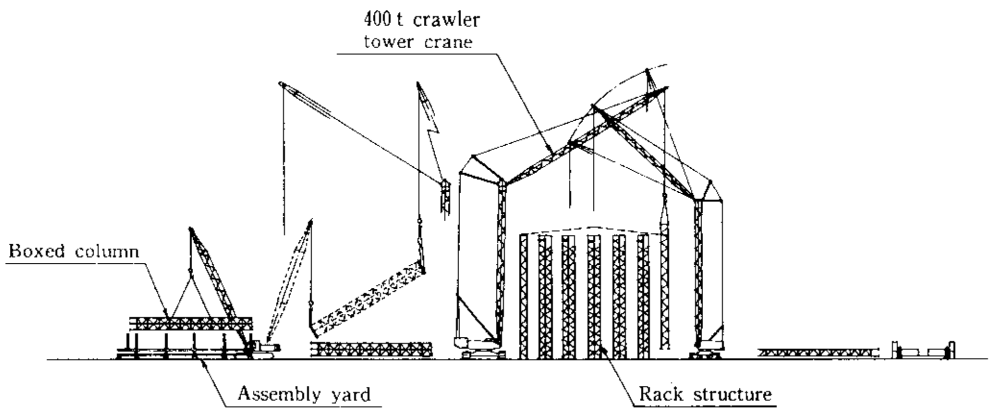

Fig. 8 Erection flow of rack structure

Photo 2 Panel erection

5 Conclusions

The high-rise rack structure was designed while comfirming anti-earthquake capacity by seismic response analysis. On the other hand, the vibration testing was also carried out.

The vibration testing has led to the following conclusions:

(1) There is little probability of coil falling down by a large earthquake.

(2) The response shear force of rack columns reduces about two-thirds due to coil and pallet's sliding.

As design methods are not established for structures that support large movable masses like a rack, seismic response simulation programs considering mass's sliding are now being developed and the rack behavior at the time of an earthquake is studied using seismograghs.

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References

1) I. Kanazawa, K. Shinto, S, Morita, M. Ikeda, K. Takahashi and K. Yoshida: "Outline of New Berth and Warehouse for Steel Products at Chiba works," *Kawasaki Steel Giho*, **18**(1986)4, 347-354

2) S. Kenmochi, T. Kimura and I. Okumura: "Construction of New Products-Berth for 80 000 DWT Vessels," *Kawasaki Steel Technical Report*, No. 17 (1986), pp. 98-103

3) S. Takahashi, H. Tanaka, I. Ichihara, H. Tahara, T. Abe and N. Hasegawa "Control System for Cargo Berth and Automated Warehouse" *Kawasaki Steel Technical Report*, No. 17 (1986), pp. 109-114

4) "The Building Standard Law of Japan"

5) Japan Soc. Ind. Machinery Manufactures: "Jishinji-Rittaijido-soko-no-Anzenka-ni-kansuru-chosakenkyuhokokusho (Research report on safety of the the rack type warehouse during earthquake)", (1981).