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Report on the damage to FRP water tanks by the Great Hanshin Earthquake

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Report on the damage to FRP water tanks by the Great Hanshin Earthquake

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Abstract—The Great Hanshin Earthquake that took place in the dawn of January 17, 1995 brought about unprecedented disasters to the Hanshin area. The size of the earthquake was recorded as a magnitude of 7.2. The acceleration observed near the epicenter was the largest in the history of earthquake observation in Japan. In this earthquake, damage that could not be explained by conventional engineering theory was observed, such as the destruction of buildings, highways and underground structures. Much damage to water tanks made of FRP were reported. However, damage to those water tanks manufactured after the revision of the earthquake resistant standards based on the revised construction standard act (1981) was much smaller than that on tanks made before the act. Damage to ceilings of many water tanks was also reported in this earthquake which were not observed previously and which therefore also characterizes this particular earthquake.

Keywords: Great Hanshin Earthquake; FIP water tank; the FRP Water Tank Earthquake Resistance Design Standard; the FRP Water Tank Structural Design Computation Method; the Building Facility Earthquake-Resistance Enforcement Guideline.

1. INTRODUCTION: OVERVIEW OF EARTHQUAKE

Some fundamental data on the Southern Hyogo Earthquake (provided by the Meteorological Agency):

(1) Name of earthquake: Heisei 7 Southern Hyogo Prefecture Earthquake.

(2) Data and time: 5:46 a.m., January 17 (Tuesday), 1995.

(3) Epicenter: Akashi Straits, about 3 km northeast of Awaji Island, latitude 34.6 north, longitude 135.0 east. Depth of epicenter: about 20 km.

(4) Size of earthquake: magnitude 7.2.

(5) Magnitude:

7: Chuo Ward, Kobe, Northern part of Awaji Island;
6: Kobe, Sumoto;
5: Toyooka, Hikone, Kyoto;
4 and less: not listed.

(6) Characteristics of earthquake.

In this earthquake, maxima of horizontal accelerations of 818 Gal (south–north) and 617 Gal (east–west), a maximum vertical acceleration of 332 Gal and a maximum displacement of 18 cm (same for both south–north and east–west) were observed by the Kobe Marine Meteorological Center located on a hard rock foundation near the epicenter. These values are the strongest ever observed in Japan. Figure 1 shows

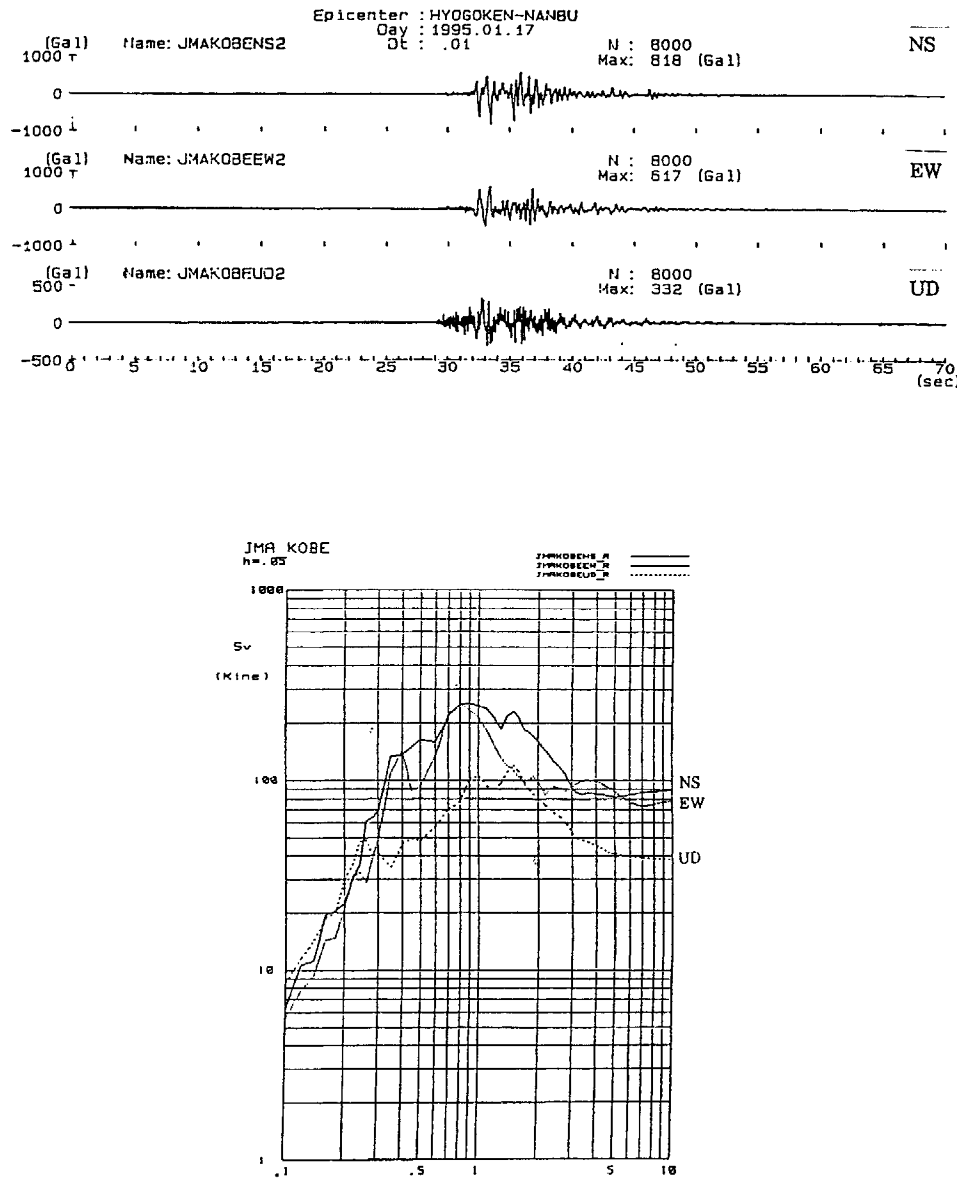

Figure 1. Recorded acceleration based on the wave forms of the earthquake (Kobe Marine Observatory).

the recorded acceleration and clearly indicates that the horizontal and vertical direct movements took place simultaneously.

Based on the waveforms of the earthquake, the following are the characteristics of ground vibration in the Hanshin area [1].

(1) In addition to the large horizontal movement in acceleration of ground vibration, the vertical movement was abnormally large. The acceleration was highly influenced by the local ground conditions.

(2) Vibration duration of the main movement was as short as 10–15 s.

(3) Eminent periods were around 1 s and 0.25–0.24 s.

(4) The ground vibration between Kobe and Nishinomiya was influenced by the geographical condition of the boundary between the plains and mountainous region so that a much larger acceleration resulted in these areas compared with that at the mountainous regions (Fig. 2).

2. SUMMARY OF DAMAGE TO FRP WATER TANKS DUE TO THE EARTHQUAKE

Table 1 shows the total number of water tanks that were requested for inspection and repair from customers by March 15, 1995 by the member companies of the Water Tank Division of the Reinforcing Plastics Association. The numbers in parentheses show the percentage of damaged number/delivered number, and the number of delivery refers to the number delivered to the Hyogo, Osaka and Kyoto areas. It was not possible to identify the number of deliveries to the area that suffered most damage by the earthquake. The percentage for the area that recorded magnitudes of 6 and 7 was not identified either.

Table 1.
The summary of damage to FRP water tank by the Great Hanshin Earthquake (P-219)

Damage	Old earthquake-resistant tanks	New earthquake-resistant tanks
(1) Water leak, but stopped with simple repair	177 tanks (1.03%)	344 tanks (0.43%)
(2) Partial damage (A); Tanks still maintained the tanks functions with partial damages	115 tanks (0.67%)	183 tanks (0.23%)
(3) Partial damage (B); Tanks no longer maintained the tanks functions with partial damage, but were repairable	48 tanks (0.28%)	10 tanks (0.01%)
TOTAL	764 tanks (4.45%)	685 tanks (0.85%)
Number delivered to the Hyogo, Osaka and Kyoto areas	17 150 tanks	80 700 tanks

( ) The numbers in the parentheses show the percentage of damaged number/delivered number.

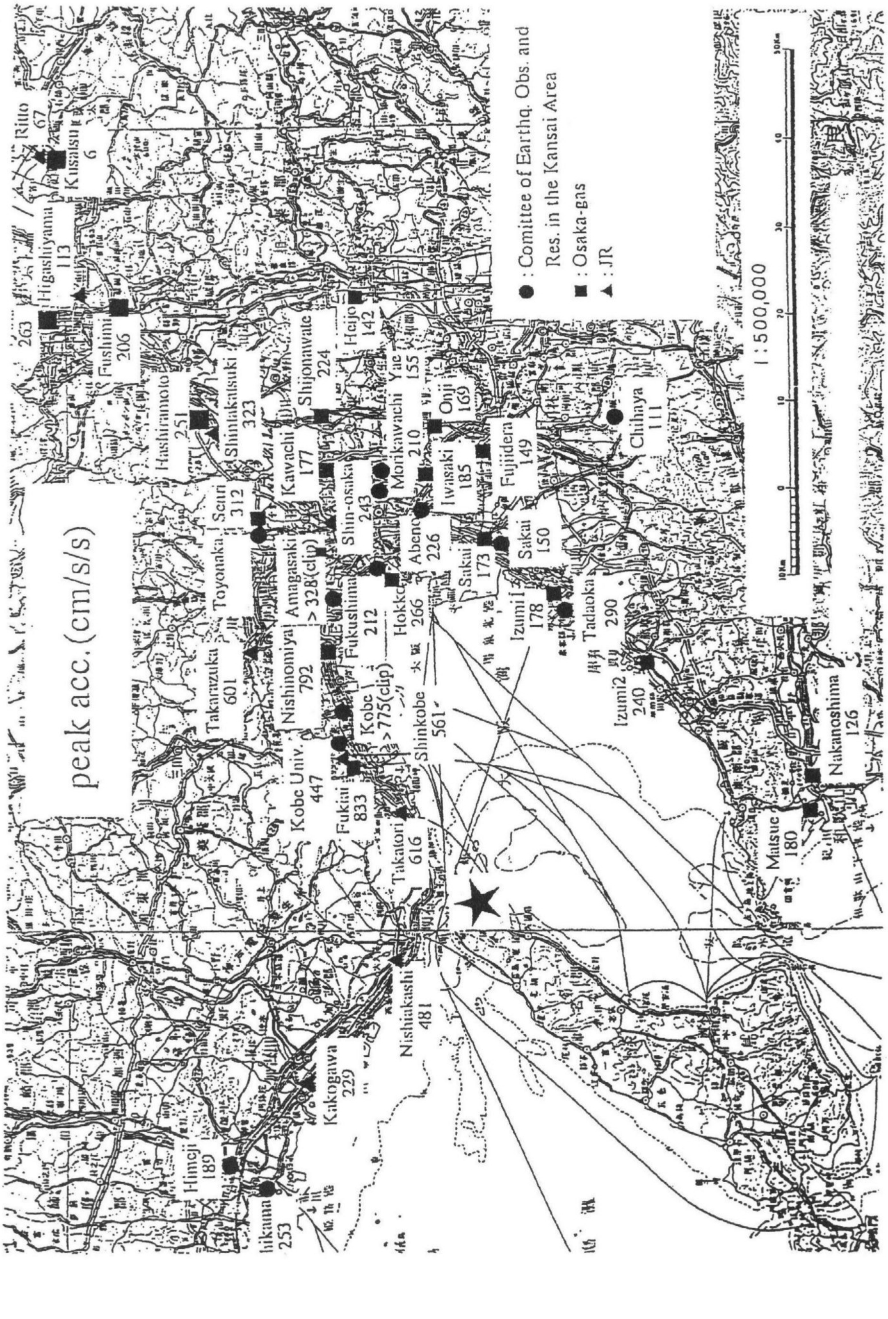

Figure 2. Distribution of the peak acceleration observed by the Committee of Earthquake Observation and Research in the Kansai Area.

Partial Damage (A) refers to those tanks that still maintained the tank functions with partial damage and Partial Damage (B) refers to those tanks that no longer maintained the tank functions with partial damage but were repairable. At the customers' request, some tanks of Partial Damage (A) and Partial Damage (B) were simply replaced instead of being repaired.

As is seen clearly from these data, there is a significant difference between those tanks that were delivered before the revision of the Construction Standard Act of 1981 (called old earthquake-resistant tanks) and those delivered after the revision (called new earthquake-resistant tanks).

The number of damaged new earthquake-resistant tanks was 685 (0.85%) while the number of damaged old earthquake-resistant tanks was 764 (4.45%). Among the totally damaged tanks, 10 were new earthquake-resistant tanks (0.01%) and 48 were old earthquake-resistant tanks (0.28%). It is seen that the damage rate of the new earthquake-resistant tanks is smaller than that of the old earthquake-resistant tanks.

Damage cases sorted according to the usage of FRP water tanks (installed location) are listed below without distinguishing old earthquake-resistant tanks from new earthquake-resistant tanks:

(1) Water receiving tanks.

(i) Uneven sinking of concrete foundations of water receiving tanks.

(ii) Anchor bolt damage at water tank supports and concrete foundations.

(iii) Shift movement from concrete foundations of water receiving tanks or supports.

(iv) Damage to connecting tubes resulting from movement of water receiving tanks and pipes.

(v) Cracks and damage on side walls of water receiving tanks and ceiling boards.

(2) High-installed water tanks and elevated water tanks.

(i) Damage to anchor bolts on high-installed water tank supports and concrete foundations.

(ii) Toppling resulting from defects of anchor bolts at steel tower supports of elevated water tanks.

(iii) Shift movement from foundations of high-installed water tank concrete foundation or supports.

(iv) Damage to main bodies of high-installed water tanks.

(v) Damage to side walls of high-installed water tanks and ceiling boards.

(vi) Water leak at high-installed water tank panel connecting parts and panel cracking.

(vii) Damage to connecting parts of high-installed water tanks and connecting tubes.

Table 2 shows the breakdown of (1) and (2) sorted by the usage, new or old earthquake-resistance standards, and damage locations. It is seen that there is a difference between old and new earthquake-resistance tanks for damage locations. Many damaged ceiling panels were found for both old and new earthquake-resistant

Table 2.
Type of tank damage due to the Hanshin Great Earthquake classified by the installation and the quake-resistant standard of FRP water tanks (P-219)

Installation of FRP water tanks		Water receiving tanks			High-installed water tanks			Elevated water tanks			Total		
		New quake-resistant tanks	Old quake-resistant tanks	Total	New quake-resistant tanks	Old quake-resistant tanks	Total	New quake-resistant tanks	Old quake-resistant tanks	Total	New quake-resistant tanks	Old quake-resistant tanks	Sum total
Damage of water tanks	Toppling-break-down	1	5	6	3	3	6	6	2	8	10	10	20
	Position shift	10	40	50	7	23	30	5	11	16	22	74	96
	Ceiling panel and side wall	7	14	21	3	9	12	4	7	11	14	30	44
	Manhole cover damage	60	30	90	28	21	49	20	5	25	108	56	164
	Side wall	33	55	88	24	30	54	27	17	44	84	102	186
	Inside division wall damage	18	16	34	13	4	17	9	1	10	40	21	61
	Inside pipe and electrode damage	21	4	25	37	5	42	31	2	33	89	11	100
	Side wall cracks	48	62	110	25	38	63	27	19	46	100	119	219
	Joint-connection	134	55	189	42	37	79	44	24	68	220	116	336
	Cock	35	51	86	28	48	76	28	17	45	91	116	207
Pipe–water tank joint	Pipe joint damage	1	0	1	0	0	0	0	0	0	1	0	1
	Pipe damage	7	41	48	11	25	36	15	21	36	33	87	120
Installation	Anchor bolt fall out	7	22	29	6	11	17	7	6	13	20	39	59
	Anchor bolt free	1	11	12	3	7	10	7	5	12	11	23	34
Total		383	406	789	230	261	491	230	137	367	843	804	1647

tanks. As the values listed in Table 2 may be counted more than once when several parts were damaged in one single tank, they do not necessarily match with the number listed in Table 1. Typical damage examples on the tanks are explained in the next section.

3. CONSIDERATION OF DAMAGE CASES OF FRP TANKS

The Southern Hyogo Earthquake was an inland local type earthquake and ground vibration duration was as short as 10–15 s. The vertical movement was as if the ground was elevated along with the horizontal movement and the eminent period was about 1 s.

In general, the characteristic vibration period of a building made of steel reinforced concrete and steel frames is about 0.5 s for 5–7 story buildings and about 1 s for 10–12 story buildings. It is estimated that the earthquake force was amplified because the eminent periods of the buildings themselves and the earthquake were so close. It is also estimated that much damage was caused because the accelerations observed at many points exceeded the design criterion magnitude of $K_{OH} = 1/3$ (about 300 Gal) and an acceleration larger than the expected earthquake resistance was applied to the water tanks.

3.1. Damage to water tanks and consideration of causes

There was a difference in degrees of damage in side walls between the old standard tanks and the new standard tanks. In the former, the side walls were not able to sustain the change in water pressure, and the cracks and damage caused destroyed the water storage function. In the latter, although water leakage was found where side walls were connected, the water storage function was maintained. This demonstrates the difference in performance between the new and old standard earthquake-resistance products.

A peculiar type of damage in this earthquake that has not been reported before was the damage to water tank ceilings. It is estimated that the water tanks were full at the time of the earthquake and that a large impact water pressure due to simultaneous horizontal and vertical movements was applied on ceiling boards.

Side walls in the water tanks were damaged or broken as they were not able to sustain the water pressure due to the damage to the ceiling boards and their mounting parts. However, even though the ceiling boards were damaged, damage to other parts was minimal and the water storage function was maintained in many cases. This fact must be taken into account for future earthquake resistant design used for water tank ceiling boards or their structures.

3.2. Damage from water tank surroundings and consideration of causes

Examples of damage due to tank mounting parts include uneven sinking of concrete foundations, and defects and strength reduction of anchor bolts. Much damage resulting from defective anchor bolts was seen in those tanks built before the revision of construction law.

Many cracks and damage at water tank side walls and bottom boards initiating at the pipe mounting parts were reported. These are the results of excessive forces applied at the mount part of tanks due to vibration of pipes. The causes of these cases are thought to be related to the presence and proper selection of flexible joints, the location, pipe support location and its mounting methods.

There were also reported cases in which although the tanks were not damaged at all, the water piping system inside the building was damaged and all the water in the tank ebbed away. Such cases imply that it is necessary to consider a water supply system as a whole from the standpoint of securing water in an emergency.

4. EARTHQUAKE PREPARATION MEASURES OF FRP WATER TANKS LEARNED FROM THE SOUTHERN HYOGO EARTHQUAKE

4.1. Earthquake-resistant design of FRP water tanks

When the Miyagi shore earthquake took place in 1978, damage to building facilities were noted, including FRP water tanks, and the earthquake resistance of FRP water tanks became an issue because of their social importance. The FRP Water Tank Earthquake Resistance Design Standard Committee was established in the Reinforced Plastics Association in 1979 after a request from the Ministry of Construction leading to the publication of the FRP Water Tank Earthquake Resistance Design Standard.

The FRP Water Tank Structural Design Committee was established in the Reinforced Plastics Association in 1980 in order to respond to the social request that FRP water tanks be made safe against external forces resulting from earthquakes and from various other forces so that they can maintain reliability. The FRP Water Tank Structural Design Computation Method was made as a result.

In 1982, the Building Facility Earthquake-Resistance Enforcement Guidelines including water tanks were published and the earthquake-resistant design of water tanks and its performance improvements have been attempted since then along with the above mentioned standard and approval.

4.2. Measures learned from the Southern Hyogo Earthquake

Major damage to water tanks includes:

(1) Damage and resultant failure of many water tank ceiling boards. Also subsequent damage and collapse of side walls.

(2) Water tank damage due to the tank mounting parts.

(3) Water tank damage due to piping connections.

However, if these cases are excluded, damage to FRP water tanks of earthquake-resistance type were very few. The following are the measures to be taken for the above three points:

(1) On water tank damage around the ceiling boards.

There are opinions that any damage to water tanks should be prevented, even that on the scale of the Southern Hyogo Earthquake. There are also differences of opinions as to whether partial damage should be allowed or not. However, the notion of a design philosophy that even with partial damage, the storing and securing of live water in an emergency can be achieved and the damage may be repaired easily at a later time seems to be reasonable and realistic. In other words, providing products that the water tanks can self-sustain even when the ceiling boards suffer damage as a result of a large-scale earthquake and the water storage function can be fully maintained and repaired easily will suit the needs of the consumers without incurring large expense.

(2) Damage due to water tank mount parts.

For damage to water tanks as a result of defects of concrete foundation and anchor bolts, measures have to be taken by examining both their design and enforcement. For example, concrete foundations can be reinforced with floor slabs as a single unit

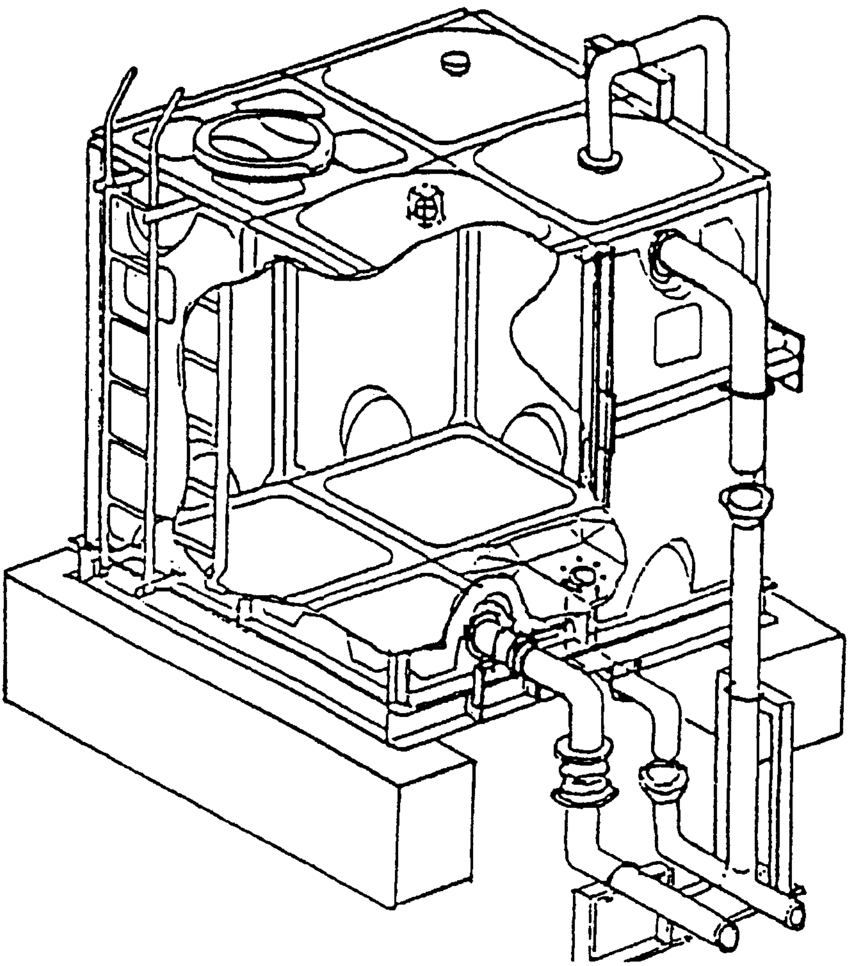

Figure 3. Example of the water tank pipe connecting parts.

and if a large pull force is present at anchor bolts, they can be welded together in the reinforcement of concrete foundations.

(3) Water tank pipe connecting parts.

It is necessary to devise a piping system so that forces due to self-weight and vibration of the piping system are not applied directly to the pipe connection parts of water tanks. It is also necessary to have flexible joints made of synthetic rubber with a berose shape and design the pipe support system so that the flexible joints are effective in three-dimensional directions. Figure 3 shows such examples.

Acknowledgements

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