RESTORATION OF ROAD AND RAIL TRANSPORTATION FOLLOWING THE GREAT HANSHIN EARTHQUAKE[1] OF 17 JANUARY 1995

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ABSTRACT

This paper describes the restoration of the rail and road routes which were seriously damaged in the Great Hanshin Earthquake of 17 January 1995. It is based on observations and data provided during a visit to Kobe, Japan in July 1995, 6 months after the earthquake.

1 INTRODUCTION

The Great Hanshin Earthquake caused major damage and disruption to the transportation systems within Kobe City and the adjacent area. The restoration of these systems is a major task requiring massive engineering, construction and financial inputs. In July 1995, the author visited the Kobe area to study the restoration works.

2 BACKGROUND

Immediately following the earthquake the New Zealand National Society for Earthquake Engineering (NZNSEE) sent a reconnaissance team to the Kobe area. A detailed report of the reconnaissance visit was published in the NZNSEE Bulletin in March 1995 [Park et al, 1995]. The report sets out in detail the damage observed to the transportation systems and the disruption caused in the first few weeks after the earthquake. A critical item for the transportation systems was the major damage to and collapses of sections of the elevated bridges, viaducts and structures supporting the highways and railways. Accordingly the NZNSEE recognised the need for a follow up visit to study the restoration work and lessons for New Zealand.

3 SUMMARY OF DAMAGE

The primary transportation links for the Kobe area are shown in Figure 3.1. These links comprise a series of expressways and railways, generally supported on elevated bridge structures. The elevated bridges suffered severe damage and collapses occurred at many locations in the areas of intense shaking.

All the primary transportation links between Nishinomiya City and Kobe City were cut, causing the remaining on-grade roads to become chaotically overloaded. Bridge collapses on the Shinkansen (bullet train) Line cut the system, isolating the northern and southern lines.

The locations where damage cut the transportation links are indicated in Figure 3.1. Further details of this damage are given in the previous NZNSEE reconnaissance report [Park et al, 1995].

4 SUMMARY OF RESTORATION WORK

The restoration programme, costs and critical repair items for reopening of routes are shown in Table 4.1.

Data is provided for the four main rail lines (JR Shinkansen, JR Trunk, Hankyu and Hanshin) and the three major expressways (Wangan, Kobe and Meishin) which provide key links in the Kobe area. Data for some other links are also indicated.

The rail links were critical as:

- loss of the Japan Rail (JR) Shinkansen lines meant that the main north south services throughout Japan were severed.
- very major financial losses were being sustained by the rail companies, both government owned and private.
- reconnection of the rail transportation links would allow large numbers of people to move about quickly again as the roads were very congested and unable to provide a satisfactory level of service.

The restoration work was carried out with urgency and as can be seen from Table 4.1 the rail links were restored rapidly.

Two Hanshin Expressway Public Corporation expressways, the Wangan Route and the Kobe Route, were also critical because of their major importance in servicing the area, and also the financial losses suffered due to the loss of toll revenues.

The Wangan Route is very new (opened in April 1994) but only goes from Osaka to as far as Rokko Island. It was less seriously damaged than the Kobe Route Expressway but sustained major damage to several of the very large bridges on the route. The restoration work was carried out with urgency and most of the Wangan expressway (as far as Ouzaki-hama near Rokko Island) was reopened on 10 April 1995.

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1 Formally designated the Hyogo-ken Nanbu Earthquake by the Japan Meterological Agency.

2 Beca Carter Hollings & Ferner Ltd, Auckland (Member)

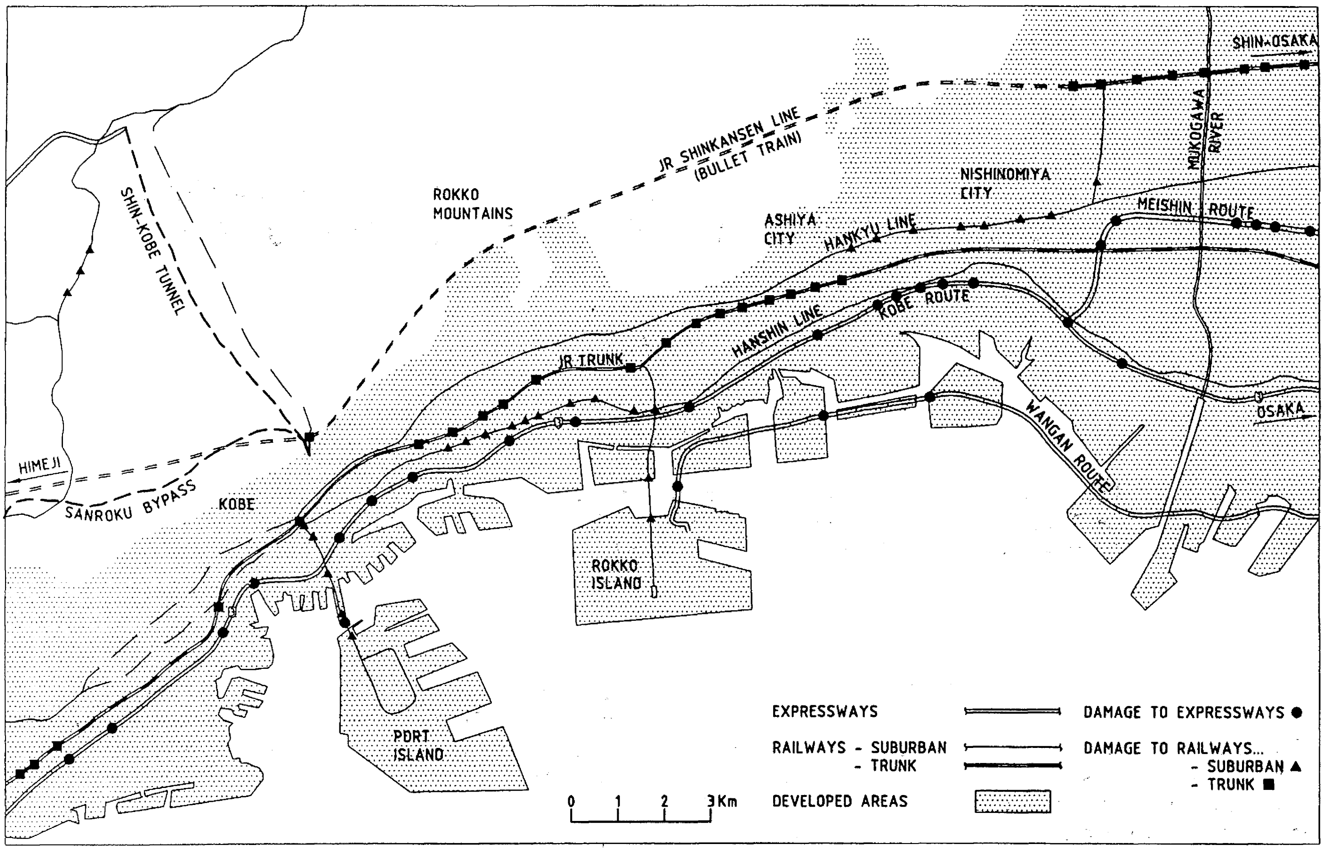


FIGURE 3.1 Damage to Primary Transportation Routes in Kobe/Nishonimya Area

TABLE 4.1 KEY DATA ON PRIMARY TRANSPORTATION ROUTES IN THE KOBE/NISHINOMIYA AREA

ROUTE	DATE OF REOPENING		NZ$MILLION		CRITICAL REPAIR ITEM FOR REOPENING
	Date	Days from Earthquake	Repair cost	Losses	
RAILWAYS					
Japan Railways Company			2000	1000	
• Shinkansen (bullet train)	8 April 1995	81			Viaduct reconstruction near Nishinomiya
• J R Trunk Line	1 April 1995	74			Viaduct/station reconstruction Nada to Sumiyoshi (2.3 Km)
Private Rail Companies					
• Hankyu Railway	12 June 1995	146	700	*	Reconstruction of 1.6 km viaduct west of Nishinomiya
• Hanshin Railway	26 June 1995	160	1000	*	Reconstruction Nishi-Nada to Mekage
HIGHWAYS					
Hanshin Expressway Public Corp (1)					
• Wangan Route Expressway	1. to Ouzaki-hama 10 April 1995 2. 31 October 1995	83	4400		Stage 1 Repair/reconstruction of Nishinomiya-Ko bridge Stage 2 Repair/reconstruction of Rokko Island bridge
• Kobe Route Expressway	1. March 1996 2. December 1996			35 per day	Stage 1 Repairs to critical viaducts Stage 2 Reconstruction of viaducts
Japan Highway Public Corp			1700		
• Meishin Expressway	31 July 1995	195			Viaduct repair/reconstruction Nishinomiya to Amagasaki IC.
• Chugoken Expressway (2)	12 February 1995	26			Temp repairs to viaducts.
Local Highways					
• Kobe Harbour Highway	August 1995				Viaduct repair/reconstruction
GUIDED BUSWAYS (to Port Is.)					
Port Island Liner	Late August 1995		*	*	Viaduct reconstruction/repair
Rokko Island Liner	31 July 1995 (to Hanshin line)	195	*	*	Rokko Island Bridge reconstruction/repair
	Total Repair Cost (3)		9800		

(1) Costs are total for all 13 routes for which Hanshin Exp Corp are responsible. Most of costs are attributable to the Wangan and Hanshin Expressways.
(2) This expressway is north of Nishinomiya.
(3) Total for items identified. Items for which data had not been received at the date of publication are shown with an asterisk.

The Kobe Route Expressway was very badly damaged and suffered many collapses. It is the most important expressway through the Kobe/Osaka area. Demolition work is complete and repairs have commenced. Due to the magnitude of work involved the expressway will be reinstated in stages. Stage 1 by March 1996 will allow some relief to traffic flows by reinstating the section nearest to Kobe. By using the Wangan Expressway and the on grade Rinkou Route as a link, traffic will more easily be able to reach Kobe. Reinstatement of the whole of the Kobe Route Expressway is scheduled for the end of 1996.

Two other expressways provide access in the Kobe/Osaka area. The Meishin Expressway is the main link to the North, bypassing Osaka. It was seriously damaged over several kilometers near its connection to the Kobe Route Expressway. By temporary propping it was able to carry 1 lane of light traffic from 1 February 1995 but was opened to 4 lanes of normal traffic on 31 July 1995. The Chugoken Expressway is an important link which skirts to the north of the Kobe/Osaka area.

There are two guided busway systems which link to the two port islands, Port Island and Rokko Island, with the primary rail transportation links. These systems were seriously damaged, and rendered inoperable.

5 DESCRIPTION OF TRANSPORTATION AUTHORITIES

Expressways

The Japan Ministry of Construction, Highways Department is responsible for public expressway corporations:

Japan Highway Public Corporation are responsible for national public expressways throughout Japan. Operations are funded by tolls and central government funding. The Corporation is responsible for the Meishin and Chugoken Expressways which were damaged in the earthquake.

Hanshin Expressway Public Corporation are responsible for public expressways in the Osaka/Kobe area. Some 200km of expressway are in operation and carry up to 930,000 vehicles per day. Operations are primarily funded by tolls. The Corporation is responsible for 13 routes including the Wangan and Kobe Routes which suffered serious damage in the earthquake.

Funding for Expressway Restoration Works

This includes emergency work, and repair and reconstruction work to reopen the routes. Japan Highway Public Corporation had funding for this work totally provided by the central government. Hanshin Expressway Public Corporation have obtained 80% of funding from central government and 10% from each of the Prefecture and City local governments. In the past, new construction work by the Hanshin Expressway Public Corporation has had 7% central government funding with the remainder from other sources. This is currently being renegotiated because of the adverse effects of the earthquake on the Hanshin Expressway Public Corporation, due to the loss of toll revenues.

Railways

Japan Rail (JR) is a government owned railway organisation, with West Japan Rail Company responsible for the JR Shinkansen (Bullet Train) line and the JR main trunk line in the Kobe/Osaka area. Funding for the emergency work, and the repair and reconstruction work to reopen the routes were provided by a government bank (at low interest rates).

The Hankyu Railways and Hanshin Railways are privately owned rail companies each with rail lines between Kobe and Osaka (and beyond).

6 RESTORATION OF RAILWAYS

6.1 West Japan Railways Corporation (JR West)

6.1.1 *Organisation*

JR West suffered heavily in the earthquake with damage restoration costs estimated at about NZ$2 billion and loss of revenue in the order of NZ$1 billion (see Shinomiya [1995]). For the restoration work a special management team was set up and the normal resources of the JR West organisation were used for the operation.

JR West carry no construction labour force and the work was carried out by construction contractors. Contractors were selected on the basis of experience and resources and contracts negotiated.

6.1.2 *Restoration of Shinkansen Line*

Operation of the line was suspended between Osaka/Kobe/Himeji, a distance of 86km, due to earthquake damage. Of this distance, 31km is tunnel, 38km is elevated framed concrete viaducts and 14km is bridge spans. Minor damage occurred to the tunnel linings at the crown in several locations. These were repaired by breaking out, installing rock bolts and reconcreting the lining. The most serious damage was that suffered by the concrete viaducts which are constructed in three span rigid framed 30 m long sections. Shear failures in the columns occurred in 144 of the 1263 sections on this route, and 13 of these 144 sections collapsed. This is illustrated in Figures 7.8 to 7.11 of Park et al [1995]. In addition, damage occurred to the piers supporting the, 14km of bridge spans at several locations (see Figure 7.12 of Park et al [1995]).

A typical three span section viaduct section is shown in Figure 6.1. In general the superstructure was not seriously damaged and because of the urgent need to reopen the line, most of the superstructure was reused. The substructure was found to be undamaged. Restoration therefore proceeded as follows. Collapsed sections (of up to 500t weight) were wherever possible jacked back into position and the supporting columns reconstructed (Figures 6.2 to 6.4). In a few cases reconstruction was required. The 800mm x 800mm columns were reconstructed by breaking back the damaged concrete to the existing bars, welding new D32 longitudinal reinforcement to the existing bars, installing column ties (D13 at 100mm centres) and reconcreting the columns. Columns not requiring reconstruction were repaired by epoxy injection. 6mm steel plate encasement was then welded in place full height around all reconstructed or repaired columns and a shrinkage compensating grout used to fill the gap between the plates and concrete. (Figure 6.5). The sections of superstructure lifted back into position were epoxy injected if appropriate and then the longitudinal beams were steel plate encased, anchors being epoxy resin anchored into the existing beams to provide extra restraint (Figure 6.6).

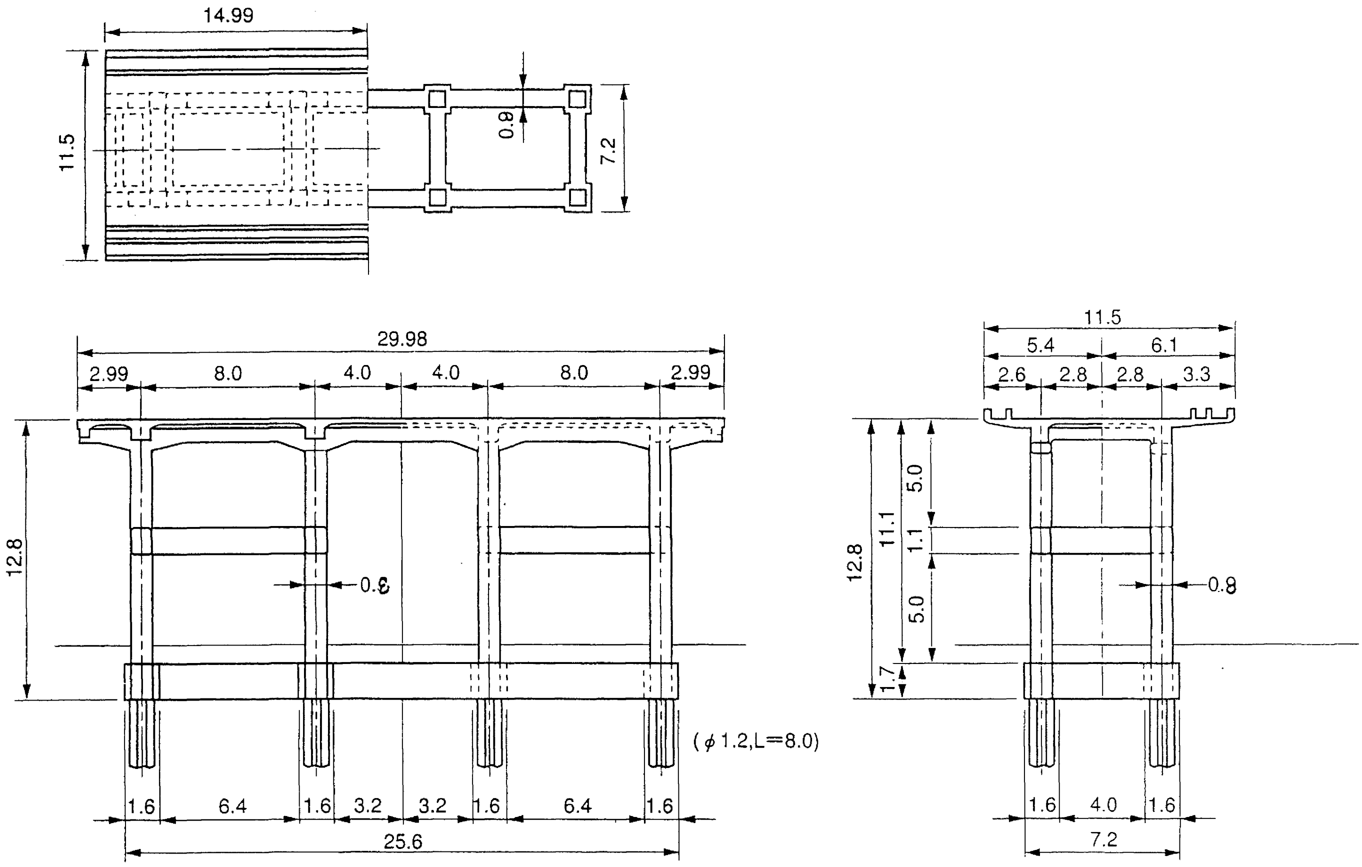


FIGURE 6.1 Typical Section of Shinkansen Viaduct

FIGURE 6.2 Shinkansen Viaduct Restoration

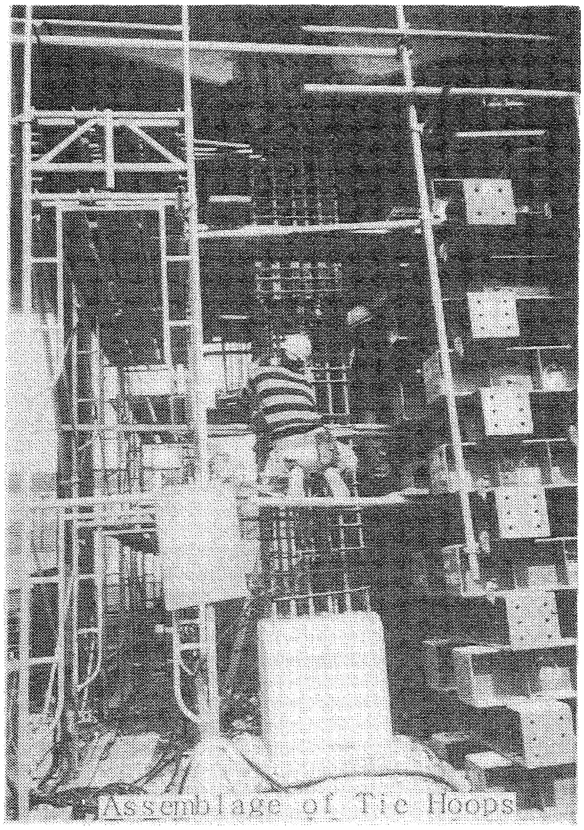


FIGURE 6.3 Shinkansen Viaduct Restoration

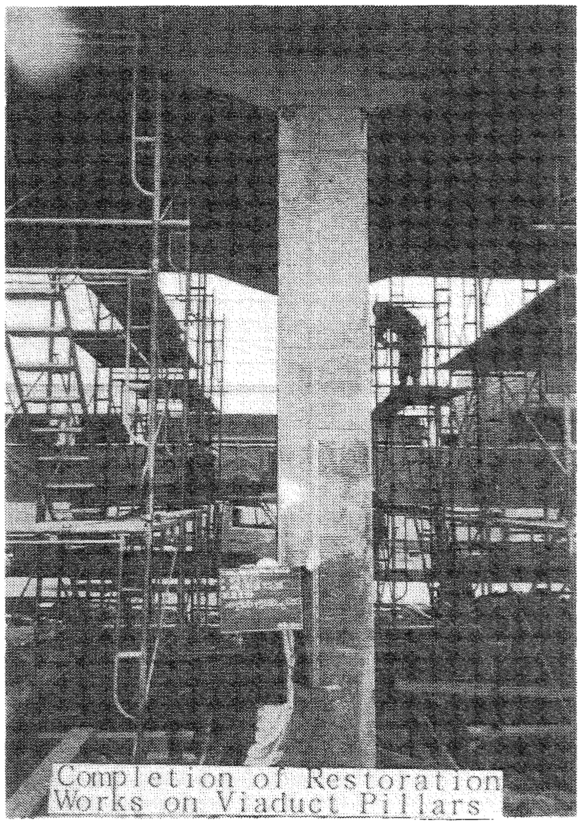


FIGURE 6.4 Shinkansen Viaduct Restoration

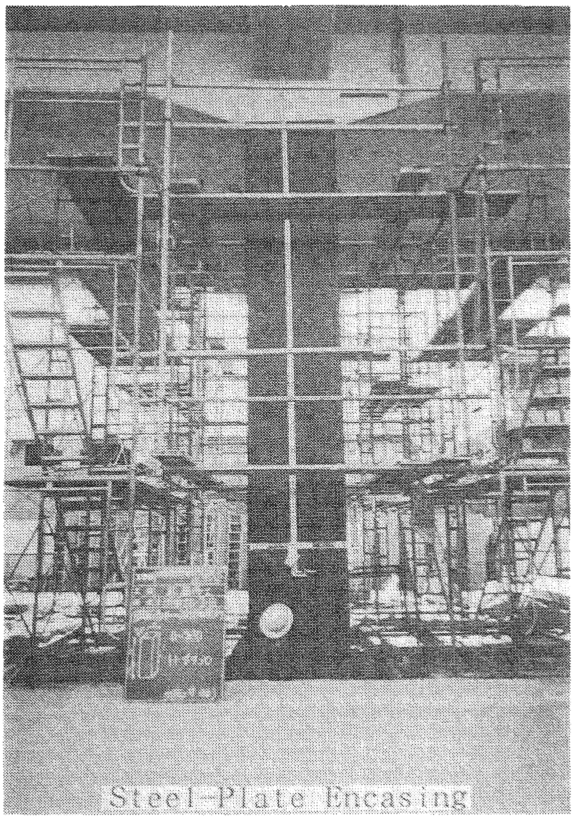


FIGURE 6.5 Shinkansen Viaduct Restoration

The damaged piers of the bridge sections of the Shinkansen were generally repaired by concrete jacketing followed by steel plate encasement. The work being carried out on the Mukogawa River bridge piers is shown in Figures 6.8 and 6.9. After epoxy injection, additional reinforcing is placed outside the column. (This reinforcement is sufficient to prevent a recurrence of the seismic shear failure caused in the column by the premature cut-off of the longitudinal reinforcement). 300mm of concrete encasement is then placed. Finally the whole pier is steel jacketed using 9mm steel plates, site butt welded together and then grouted into position.

On completion of the structural work the ballast, tracks, electrification and signalling work were completed and the line reopened 81 days after the earthquake.

The restored structure is shown in Figure 6.7. The columns are steel encased but the mid height beams are not.

6.1.3 *Restoration of JR Trunk Line*

The JR trunk line suffered heavy damage to the railbed, viaducts, bridges, stations, electrification system and workshops. Services on the line were restored progressively with sections being opened in stages. Bus services were provided for passengers between the stations at the railhead of the operating rail sections. In several cases, due to station and platform damage, temporary facilities were provided. The critical section for the restoration work was the 2.3km long elevated viaduct section between Sumiyoshi and Nada stations which suffered

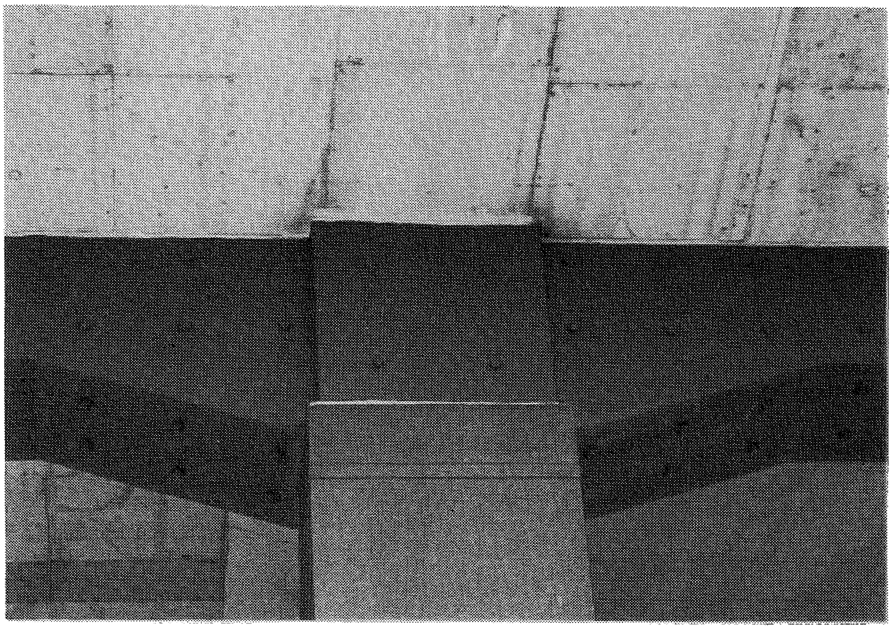


FIGURE 6.6 Shinkansen Viaduct Superstructure Restoration

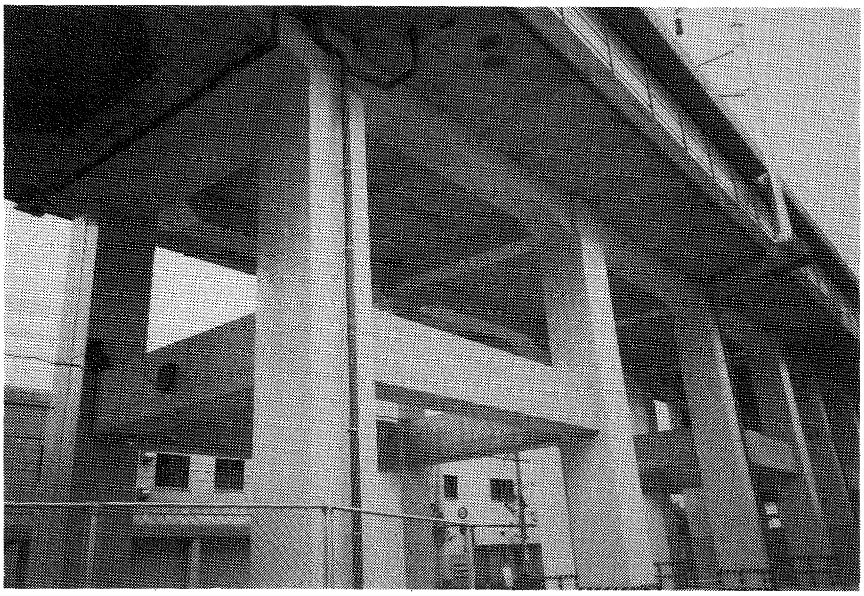


FIGURE 6.7 Restored Shinkansen Viaduct

severe column damage and collapse of several sections. Restoration works included column reinstatement and jacketing with 6mm steel plates in a similar manner to the Shinkansen line described above. The complete line was opened on 1 April 1995, 74 days after the earthquake.

6.1.4 *Railway Bridge Design Standards*

The Shinkansen line was constructed in 1970. It was designed to the 1958 Railway Bridge Design Standard. The columns were specified to have 9mm diameter single perimeter ties at 150mm centres in the end regions (over a length of twice the column dimension) and at 300mm centres elsewhere. This significantly exceeded the requirements of the 1958 standard which required single perimeter ties with a minimum size of 6mm and maximum spacing not exceeding the least of:-

- the column dimension
- 12 x the longitudinal bar diameter
- 48 x the tie diameter

Clearly this standard would lead to light widely spaced ties, essentially providing no increase in ductility and leaving the columns vulnerable to shear failures. Most of the rail viaducts and bridges in the Kobe/Nishinomiya area are understood to be older than the Shinkansen line and to have been designed to the 1958 Standard. The 1958 Standard required a seismic design lateral load of 0.2g to be applied using working stress design methods. Allowable steel stresses were 1,600kg/cm^2 (163 MPa) for the Shinkansen and 2000 kg/cm^2 (203 MPa) for other rail lines.

The design standards for rail bridges have been revised at regular intervals since 1958. Several of the most significant revisions are noted below.

1970 Standard. This required column ties to be anchored inside the column core. (Prior to this they could be anchored in the cover concrete).

1979 Standard. This required column ties to be not less than 13mm diameter and spaced not more than 100mm centres over the end regions of the columns (defined as twice the column dimension). In addition, minimal area of the steel was required to be 0.2% of column area and extra transverse ties were required for columns exceeding 1m in size.

1991 Standard. This required ultimate strength design and in addition to the requirements of previous standards it required column tie steel to be provided for the calculated shear and an additional tie area of 0.05% of the column area be added. Requirements for beam stirrups and ties to provide confinement were also added.

6.1.5 *Design Standards for Restoration Work*

The restoration work needed to proceed urgently after the earthquake to allow the rail lines to be reopened. It was therefore necessary to establish the design standards for the reconstruction work at an early stage. Accordingly, a design and construction procedures manual was prepared by JR West, the first draft being completed on 24 January, 7 days after the earthquake! The Transportation Ministry at this time set up "The Committee for Earthquake-Resistant Railway Facilities" with a brief to propose effective measures for improving the earthquake resistance of the railway structures and to verify procedures proposed for the restoration and retrofitting of the rail bridges. The committee is chaired by Professor Matsumoto of the Railways Technical Research Institute in Tokyo.

The design standards used for the restoration work were developed and agreed by JR West and the "Matsumoto" Committee. The restoration design standards and procedures initially proposed by JR West were as follows:

For the multicolumn concrete viaducts -

(i) Reconstruction to the current railway design standard of all collapsed or seriously damaged structures. This typically required single 13mm ties at 100mm centres for the 800mm square Shinkansen columns.

(ii) Repair by epoxy injection of all areas with minor damage.

For the single column river bridges -

Repair to achieve current design standards by encasing damaged piers with reinforced concrete designed to mitigate shear and flexural failures primarily associated with the cutoff of the flexural reinforcement. This typically required 300mm of concrete reinforced with full length 29mm diameter vertical bars anchored into the foundations and 22mm hoop bars at 150mm centres in the pier column end regions and 100mm between, to for example, the Mukogowa River Bridge piers. (Figure 6.8).

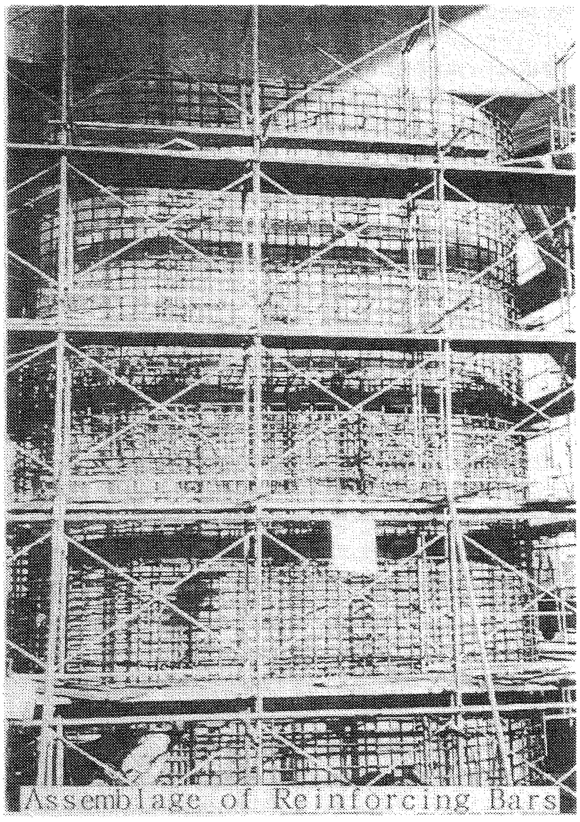


FIGURE 6.8 Mukogawa River Bridge Restoration

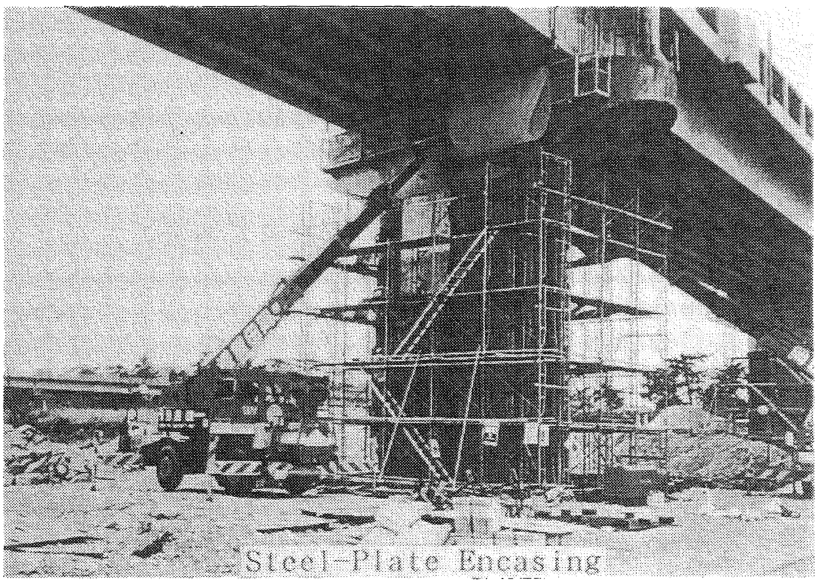


FIGURE 6.9 Mukogawa River Bridge Restoration

The restoration work was initiated on this basis, however there were still concerns about whether the structures would perform satisfactorily in another earthquake with similar levels of shaking to those of the Great Hanshin Quake. To address this matter a testing programme under the direction of the Matsumoto Committee was initiated.

The test programme involved four full size tests of the 800mm x 800mmm column sections used on the concrete viaduct sections of the Shinkansen. A 3m height from the fixed base to inflection point was chosen as the column test simulates a typical 6m high Shinkansen column. Details of the test specimens are given in Table 6.1 and Figure 6.10(a) below. The testing regime is shown in Figure 6.10(b).

Test results for specimens 1 and 2 are shown in Figure 6.11 As would be expected in the plastic hinge region at the base, the columns grew in dimension as the confining plates were loaded, specimen 2 reaching about 1000mm x 1000mm in size. The assessed ductility capability of the specimens is set out in Table 6.2 below.

As a result of the test programme the Matsumoto Committee recommended that all columns on damaged viaducts be encased with 6mm plate as the 5 fold increase in ductility over the original columns would meet the objective of ensuring satisfactory performance in an earthquake shaking level corresponding to the Great Hanshin Earthquake. These recommendations were adopted by JR West and applied to all viaduct structures on the JR Shinkansen and also the JR trunk lines. For the river bridge piers a 9mm plating over the 300mm concrete encasement was adopted.

6.1.6 *Retrofitting*

The 200km section of the Shinkansen line between Osaka and Okayama (to the south west of Kobe) is constructed to the standards described for the 86km Himeji/Osaka section above. There are many columns (ie up to 30%) which are assessed as having low shear capacity by the current design standard and therefore potentially requiring retrofit. Railway companies in Japan are surveying their lines to find the most vulnerable sections, concentrating most urgently on columns which have inadequate shear capacity. The Matsumoto Committee has recommended these be identified and retrofitted within the next three years. Methods being studied for retrofitting include steel jacketing and various other wrapping methods.

6.2 Hankyu Railway

Restoration

The privately owned Hankyu Railway Company was seriously affected by the earthquake, losing an important part of its network and requiring NZ$700 million of restoration works. As with the JR trunk line the Hankyu line was restored in stages.

The most critical section of the Hankyu line both in terms of programme and restoration cost was the 1.6km length located 0.5 km west of Nishinomiya which was seriously damaged with severe column shear failures and collapses of several viaduct sections occurring. The original structure comprised a reinforced concrete viaduct constructed in 36m sections with 6m span lengths, refer Figure 6.12(a). This structure was demolished and replaced with the structure shown in Figure 6.12(b).

Table 6.1 Test Specimens - JR Shinkansen

Specimen No.		1	2	3	4
Column Size		800mm x 800mm			
Longitudinal Reinforcing		20 D32 (p = 0.80%)			
Ties	End Region	ϕ9 (Plain) @ 150mm (p = 0.11%)			
	Elsewhere	ϕ9 (Plain) @ 300mm (p = 0.05%)			
Steel Plate Encasement		-	6mm	9mm	-
Applied Axial Load		240t	240t	240t	variable*

* Simulates load changes of a bent under transverse seismic load.

Table 6.2 Assessed Ductility Capability

Specimen No.	Yield Displacement δy mm	Ultimate Displacement δu mm	Assessed Ductility μ
1	21	43	2
2	13	140	11
3	11	172	15

Where $\mu = \delta u/\delta y$

δu = displacement at which test load has fallen to load at δy

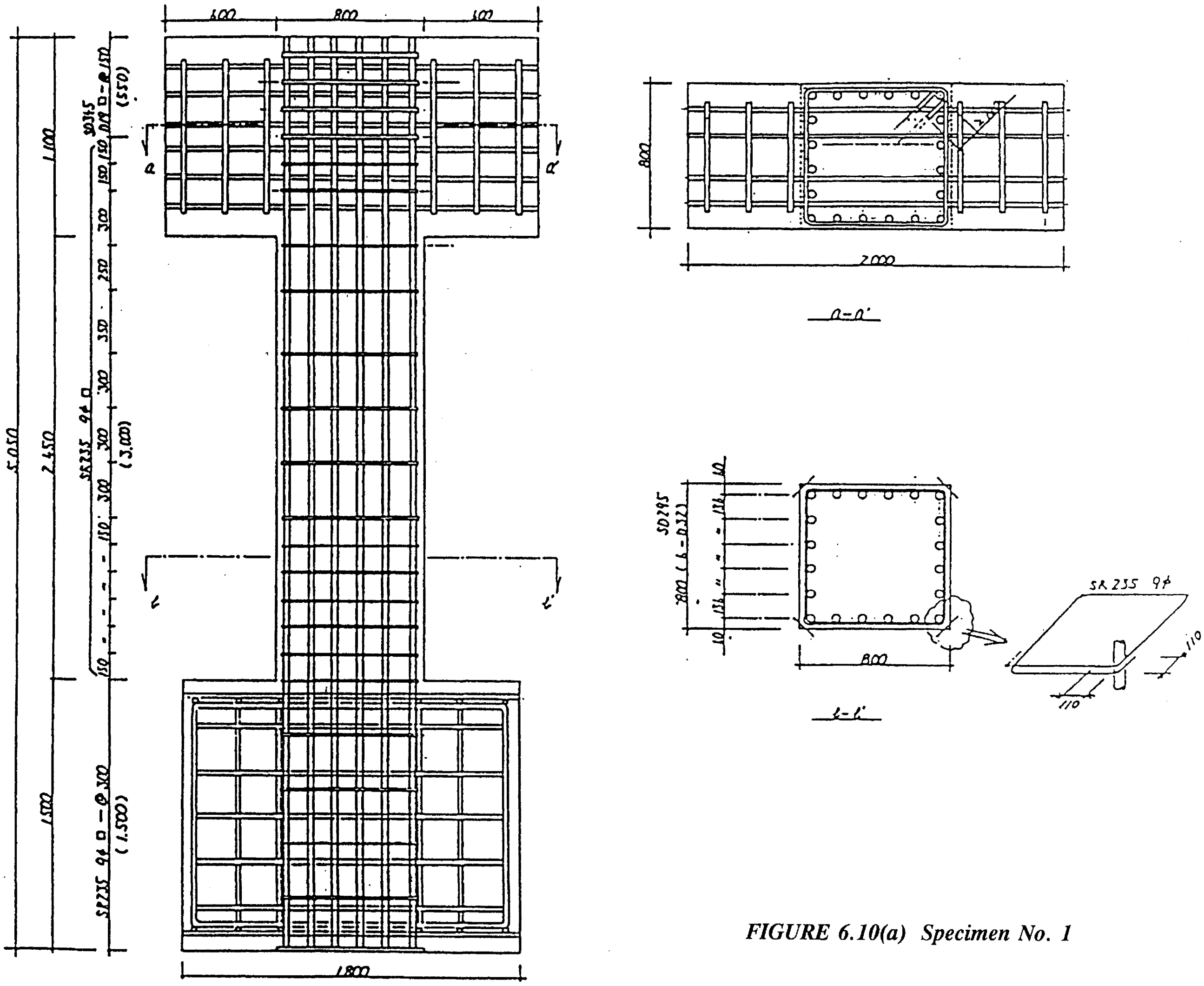


FIGURE 6.10(a) Specimen No. 1

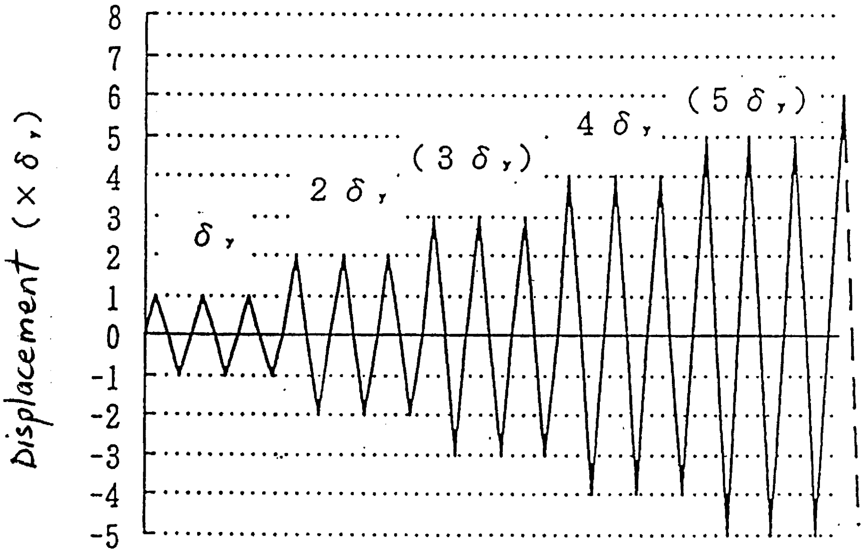
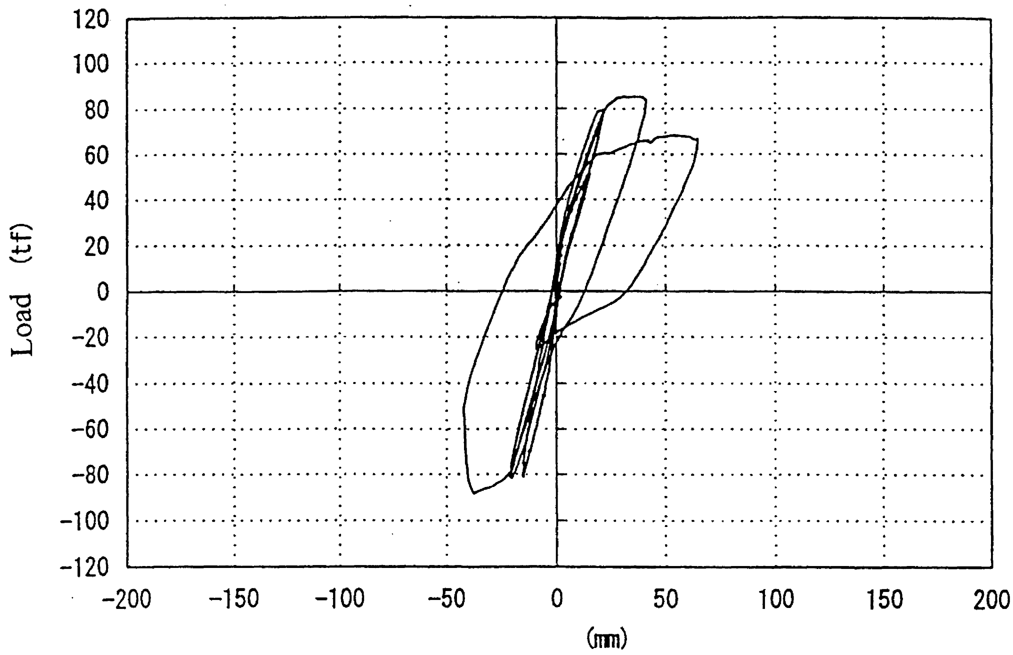


FIGURE 6.10(b) Testing Regime

(a)Specimen No. 1



(b)Specimen No. 2

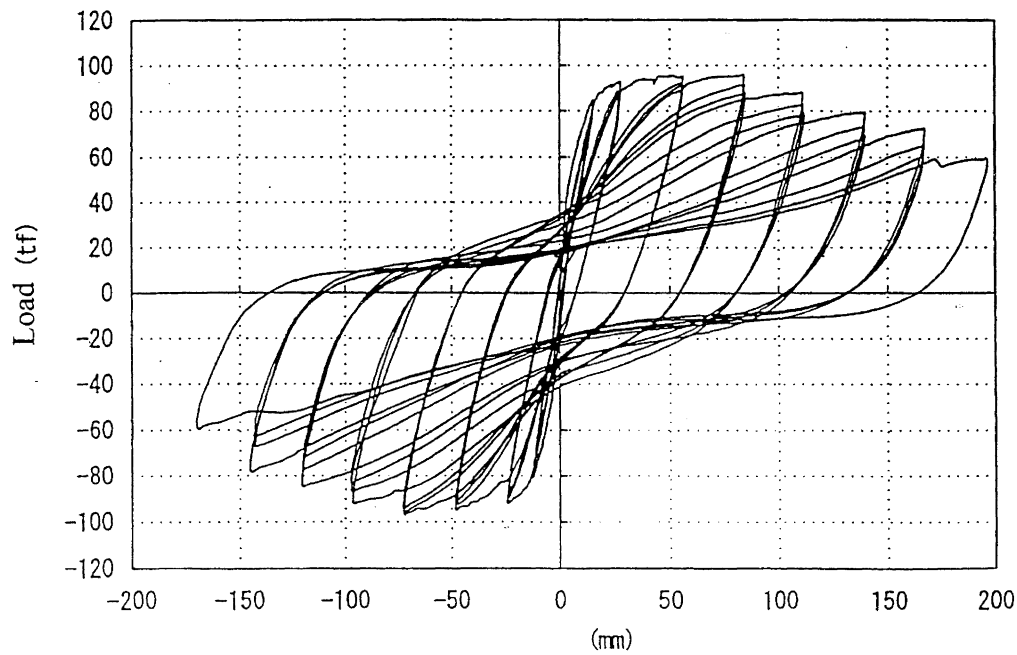


FIGURE 6.11 Test Results Specimens 1 & 2

The chosen structural system was composite steel reinforced concrete (SRC). Steel I beams were used for the foundation beams and the superstructure and steel cruciform sections for the columns. Ties and stirrups were then placed and the concrete placement completed. The construction is illustrated in Figures 6.13 and 6.14. Steel jacketing of bridge piers which were retained was also carried out as shown in Figure 6.15. Design work by engineering consultant Nikken Sekkei commenced on 20 January, three days after the earthquake. Operation of the full line occurred on 6 June 1995, 146 days after the earthquake.

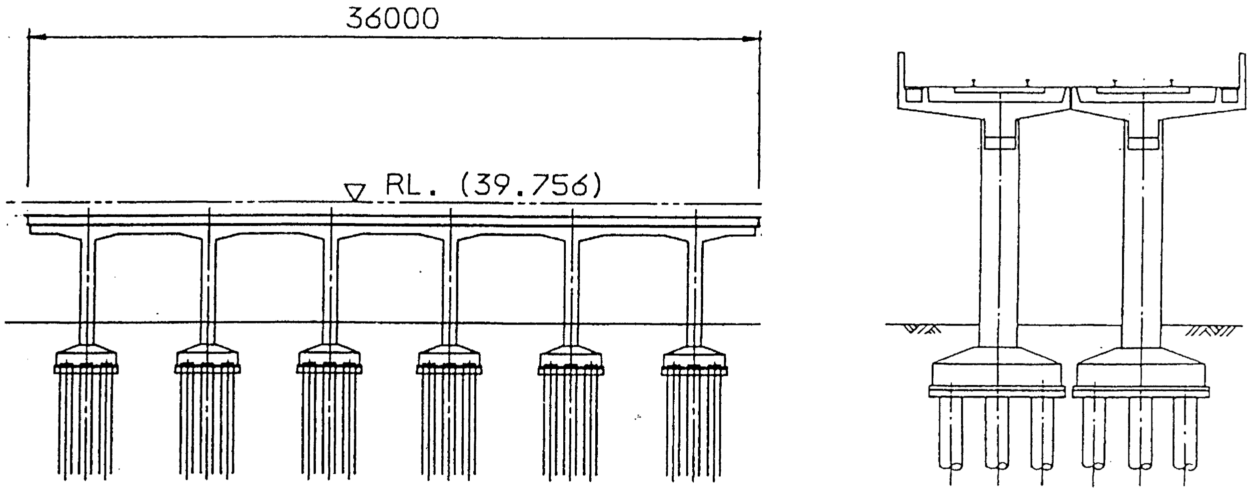


FIGURE 6.12(a) Hankyu Railway - Original Viaduct

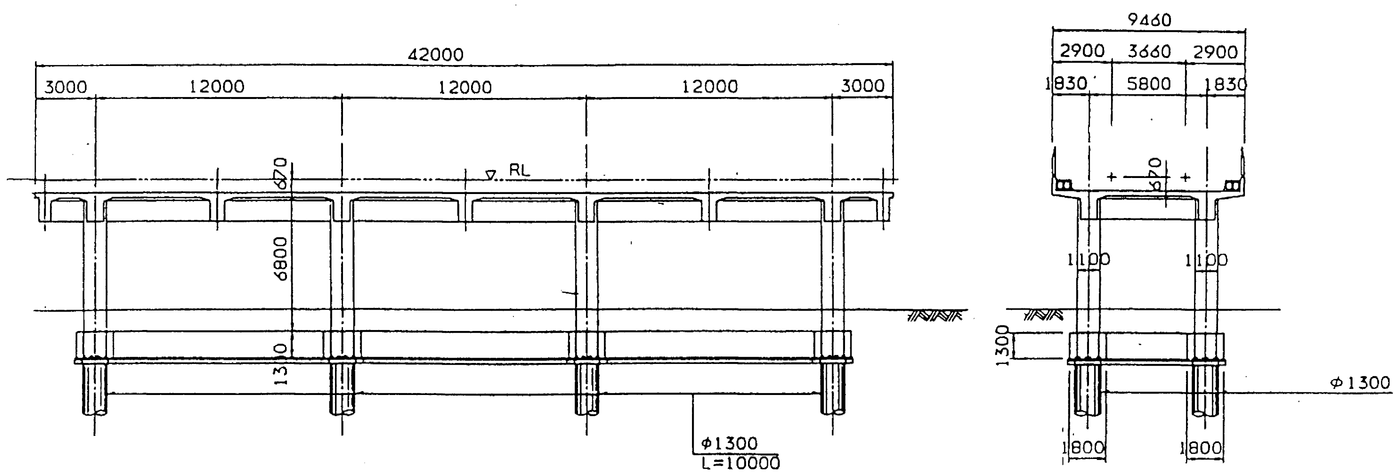


FIGURE 6.12(b) Hankyu Railway - Replacement Viaduct

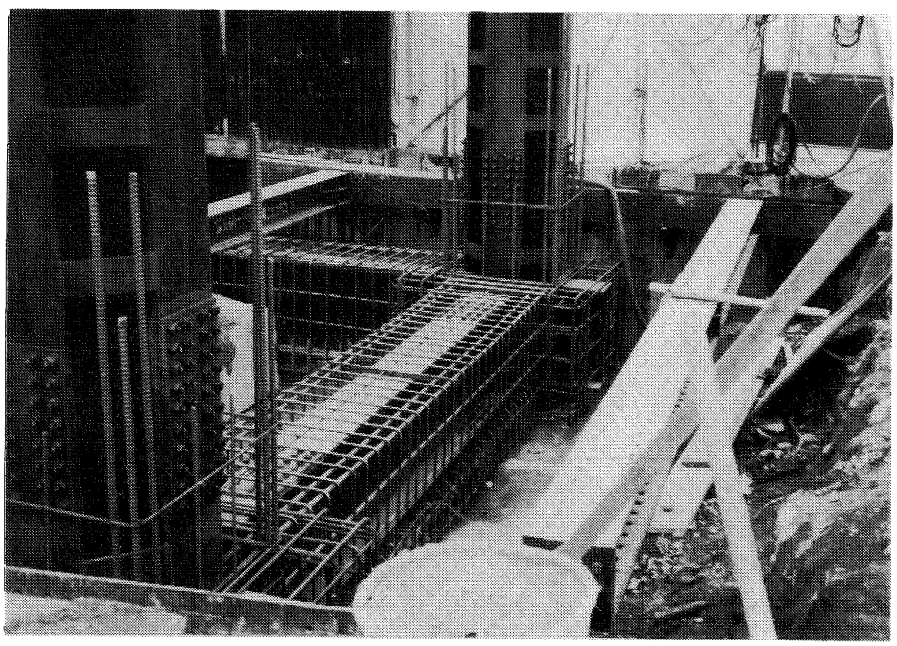


FIGURE 6.13 Hankyu Railway - Replacement Viaduct

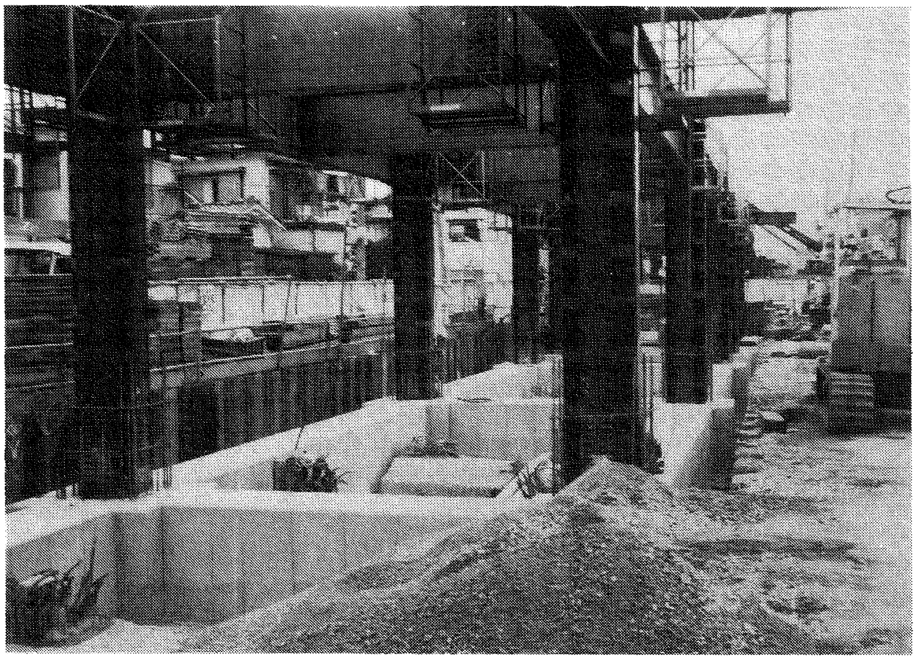


FIGURE 6.14 Hankyu Railway - Replacement Viaduct

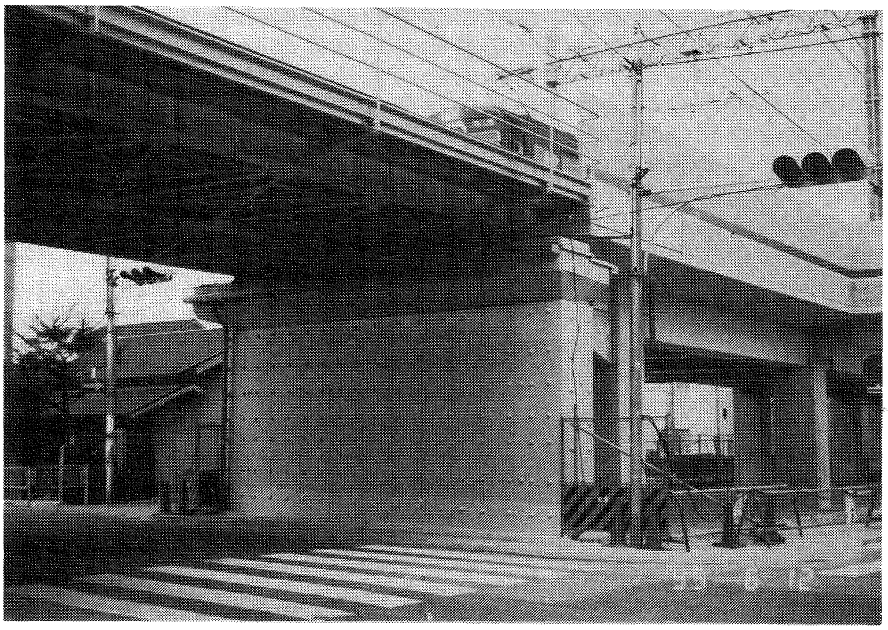


FIGURE 6.15 Hankyu Railway - Steel Jacketing of Existing Bridge Pier

Design Standards and Philosophy

As with the other rail facilities there was intense pressure to reopen the facility and design philosophy and standards needed to be established at an early stage. The design philosophy adopted was:

- Damage in a large earthquake (ie equivalent to the Great Hanshin) must be small.
- The facility must be able to continue operation without disruption in such an event.

Because of concerns about concrete columns being able to meet the philosophy above it was decided to use steel columns. The cost penalty of the more expensive steel structure was considered acceptable. The design was carried out to the current Railway Bridge Design Standard but a seismic lateral force level of 0.3g was used instead of the 0.2 specified. In addition the performance of the structure was checked by carrying out time history analyses using appropriate earthquake records from the Great Hanshin Earthquake.

7 RESTORATION OF HIGHWAYS

7.1 Hanshin Public Expressway Corporation (HPEC)

7.1.1 *Organisation and Emergency Response*

The HPEC operate sophisticated traffic control systems on their expressway system including vehicle detectors, monitoring cameras and electronic traffic information boards. These also form part of the HPEC Disaster Prevention Procedure which was implemented immediately following the earthquake. The implementation of the emergency procedures and the organisation adopted are shown in Figure 7.1.

A critical item was the urgent implementation of temporary measures to open up and to protect traffic on the routes adjacent to and beneath the damaged expressway structures. Some critical collapsed sections required removal and long lengths of the expressway required temporary securing to allow initially emergency traffic and later normal traffic to access the Kobe/Nishinomiya route. This was especially critical for the Kobe Route which runs above the on grade Highway 43 (refer Figure 7.2).

Demolition of the 600 mm section of concrete structure which had collapsed sideways on to Highway 43 (Figure 7.2 of Park et al [1995]) was a high priority and was completed by the first week of February. Installation of temporary supports (Figure 7.3), temporary connections to prevent further collapse (Figure 7.4) and temporary strengthening to the bases of severely damaged columns using steel plates with concrete placed behind them (Figure 7.5) were completed at an early stage. The loss of the Wangan Route, and more critically the Kobe Route, severely impacted on traffic flows in the area. The measures described above were designed to allow the earliest possible resumption of the traffic flows.

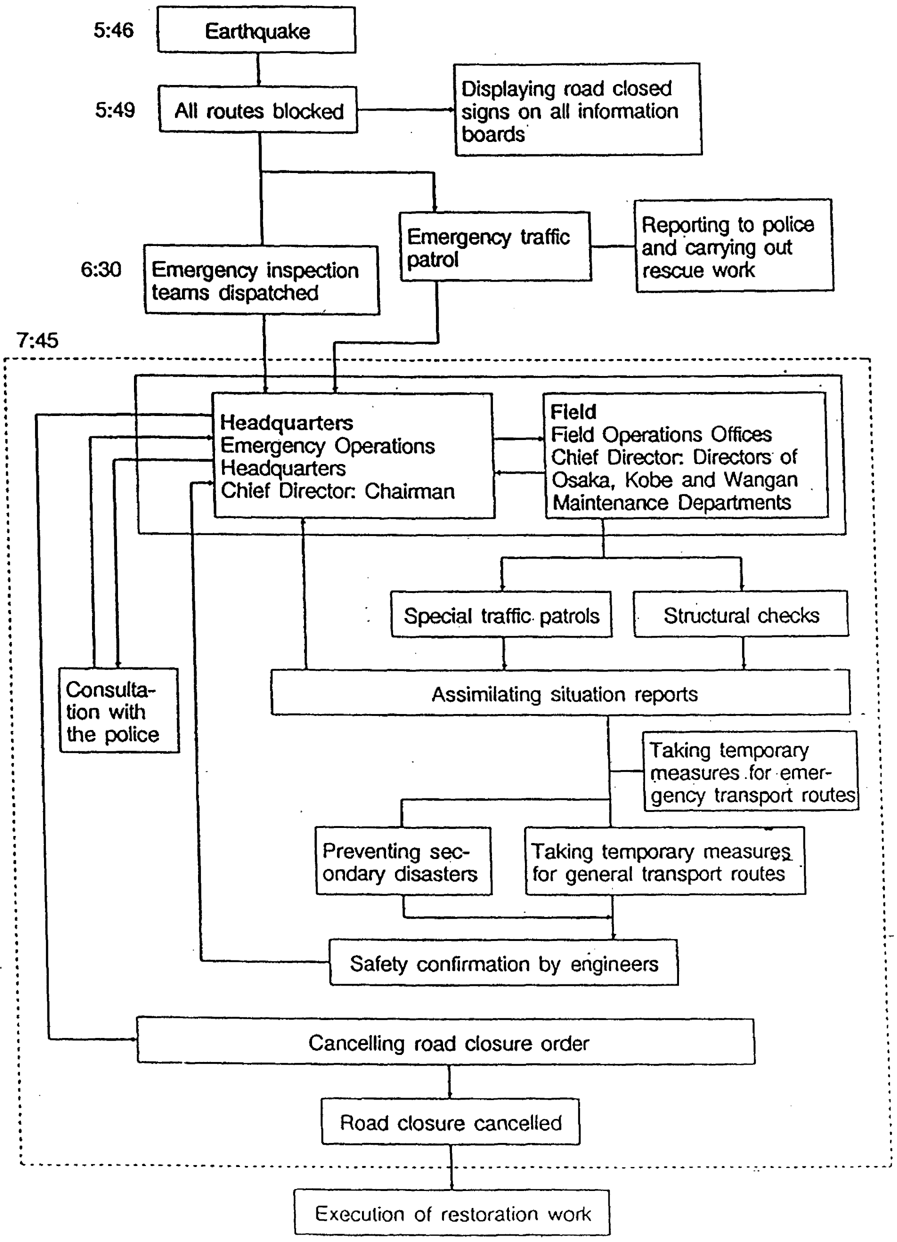


FIGURE 7.1 Emergency Procedures and Organisation After the Earthquake - Flow Chart

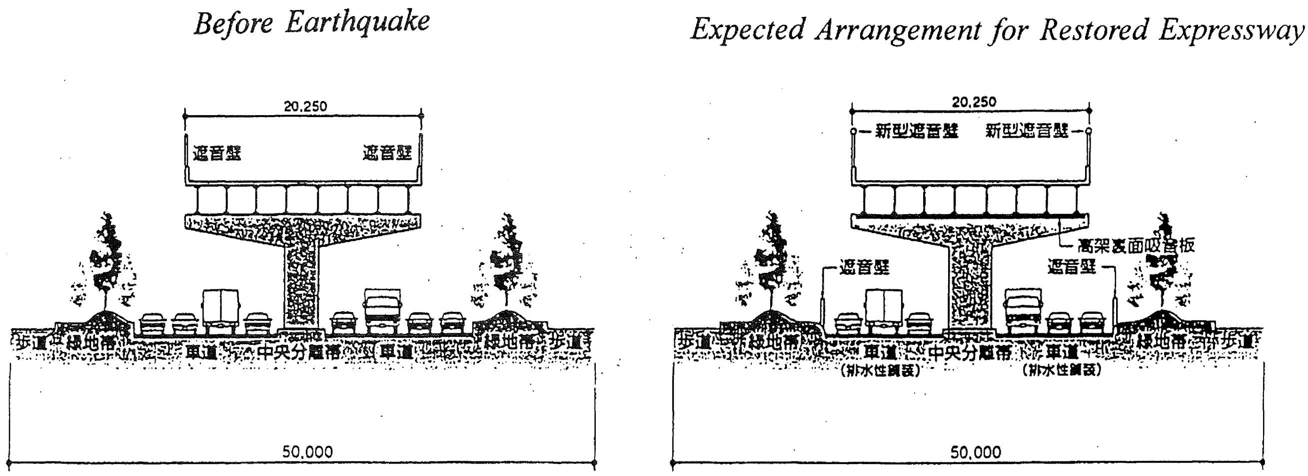


FIGURE 7.2 Kobe Route Expressway

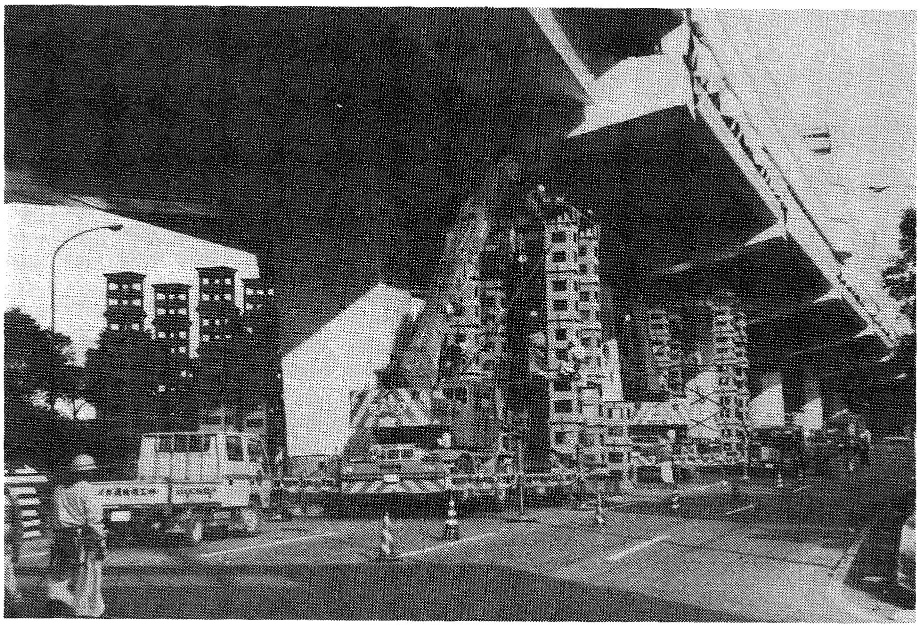


FIGURE 7.3 Kobe Route - Temporary supports

7.1.2 *Restoration Policy*

After the earthquake HPEC were faced with two elevated expressways, both vital to the Kobe/Nishinomiya area and needing to be urgently reopened. The Wangan Route (opened in April 1994) was designed to the "modern" 1980 and 1990 Bridge Design Standards and suffered damage (including a span collapse) to the 5 major bridges. The Kobe Route, designed to the 1964 and 1971 bridge Design Standards suffered damage to a significant proportion of the bridge piers and the collapses which occurred at 14 locations on the Nishinomiya/Kobe section, involved about 10% of this part of the expressway (see Mikitake et al [1995] for further details).

It was apparent that the Wangan Route could be reinstated in a relatively short time period whereas the Kobe Route would take much longer because of the extent of damage, the difficult working conditions, (i.e. over an existing highway critical to the region) and the inherent problems of a structure designed to the old seismic standards. Accordingly, HPEC policy was to concentrate the restoration effort initially on the Wangan Expressway.

HPEC assembled Restoration Policy documents for the restoration work. A brief summary of the policy document for the Kobe Route is as follows:-

Principles
- Reopen expressways as fast as possible.
- Restore bridges to a standard such that they can withstand an earthquake equivalent to the Great Hanshin Quake.
- Provide safety for vehicles using roads under the restoration works.

Design Standards
- In accordance with the Ministry of Construction ("Restoration Specifications" (refer to section 7.3 below).

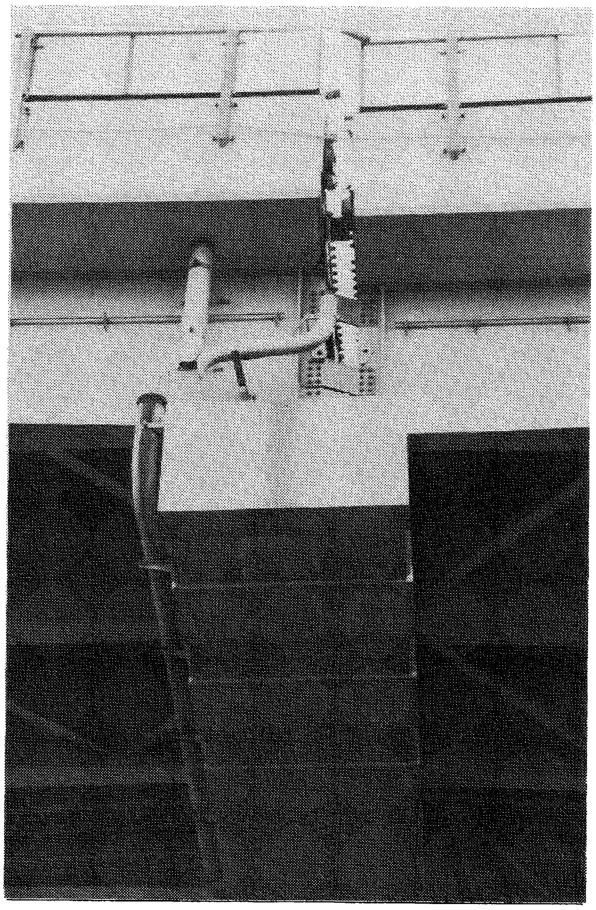


FIGURE 7.4 Kobe Route - Temporary Girder connections

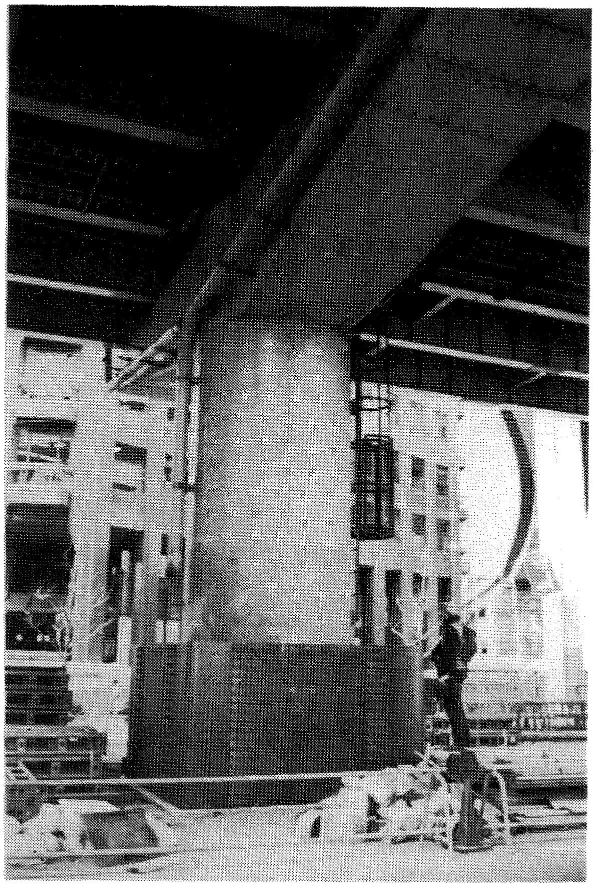


FIGURE 7.5 Kobe Route - Temporary Column Base Strengthening

Design Principles
- To be as set out in Table 7.1 below.

Environmental and Traffic
- Maintain traffic volumes on adjacent highway as far as possible.
- Reuse demolition debris in reconstruction work as much as possible.
- Try to be in harmony with the environment.

7.1.3 *Restoration of Wangan Route Expressway*

This expressway, designed to modern standards suffered damage to 5 of the major watercrossing bridges nearest to the earthquake epicentre.

The two most critically damaged bridges were the Nishinomiya-ko and the Rokko Island Bridges. The collapsed span and damage to the Nishinomiya-ko Bridge (Figures 7.13 and 7.14 of Park et al [1995]) prevented access to the western part of the expressway. The damage to the Rokko Island Bridge, inoperable because of a 3.1m movement of the superstructure transversely on a pier, prevented expressway access to Rokko Island.

The restoration work was carried out in two stages. The first following completion of repairs to the Nishinomiya-ko Bridge on 10 April 1995, opened up the expressway from Osaka to Ouzaki-hama allowing traffic better access the Kobe/Nishinomiya area. The second stage of the works was restoration of the Rokko Island Bridge which allowed the complete expressway to open in late October 1995.

The Nishinomiya-ko Bridge is illustrated in Figure 7.6. The massive caisson foundations are founded on a gravel layer. The upper half of the caisson is surrounded by reclaimed material while the lower half penetrates very soft marine mud. The reclamation is a sandy material (a highly weathered granite) which showed evidence of liquification and lateral spreading at the margins in the earthquake. Both the reclaimed material and marine mud have low standard penetration test blow counts. After the earthquake measurement showed the top of the caisson had moved 90 mm westward (toward the sea) and the top of the steel framed pier had moved 170 mm westward. On 24 February the collapsed span was removed in three pieces using a floating crane in the adjacent seaway. Repairs to the bridge to receive a new span were carried out including installation of new bearings and a seat extension to the pier. The replacement span comprised 3 steel boxes similar to the original but the total construction weight was lighter because a steel deck was used instead of a concrete deck. The 800t span which had been barged to site was lifted into place on 18 March 1995 using a 4100 t floating crane.

Completion of this work allowed the Wangan Route to be opened to Ouzaki-hama on April 10 1995. Note that while the work described above was being carried out, very substantial repair works were performed on the other damaged bridges on the route.

TABLE 7.1 Design Principles for Restoration Work

Category		Rebuilding	Reinforcing
Concept		Remove existing structures and build new structures satisfying the Restoration Specifications.	Reinforce existing structures for higher seismic resistance that meets the Restoration Specifications.
Foundations		Evaluate the severity of damage and rebuild if necessary.	Examine damage based on the Restoration Specifications and add piles if necessary.
Substructures (piers)	Reinforced concrete	Retain the original cross-sectional shape, either circular or rectangular, and determine the new cross-section in accordance with the Restoration Specifications.	Retaining the original shape, repair damaged parts and reinforce them by encasing the piers with concrete 20 to 30 cm thick. Add steel-plate casing, depending on the severity of the damage, structural factors and the conditions at the site.
	Steel	Retain the original cross-sectional shape, either circular or rectangular, and determine the new cross-section in accordance with the Restoration Specifications. Fill the piers with concrete.	Repair damaged parts including cracks and buckling, and add concrete inside the piers for reinforcement.
Superstructures (girders)	Steel	Build continuous girders, retaining the original design.	• Repair damaged parts, recycling as many existing members as possible. Cut or remove the damaged ends from girders and replace them with new members as necessary. • Reinforce the end lateral girders if necessary. • Connect the girders whenever possible.
	Concrete	Build continuous steel girders.	• Repair damaged parts.
Decks		Use steel decks.	• Repair damaged parts including crack and add steel plates and epoxy for reinforcement. • Use steel decks for recycled girders.
Bearings		Use base isolators only.	• Install as many base isolators as possible.

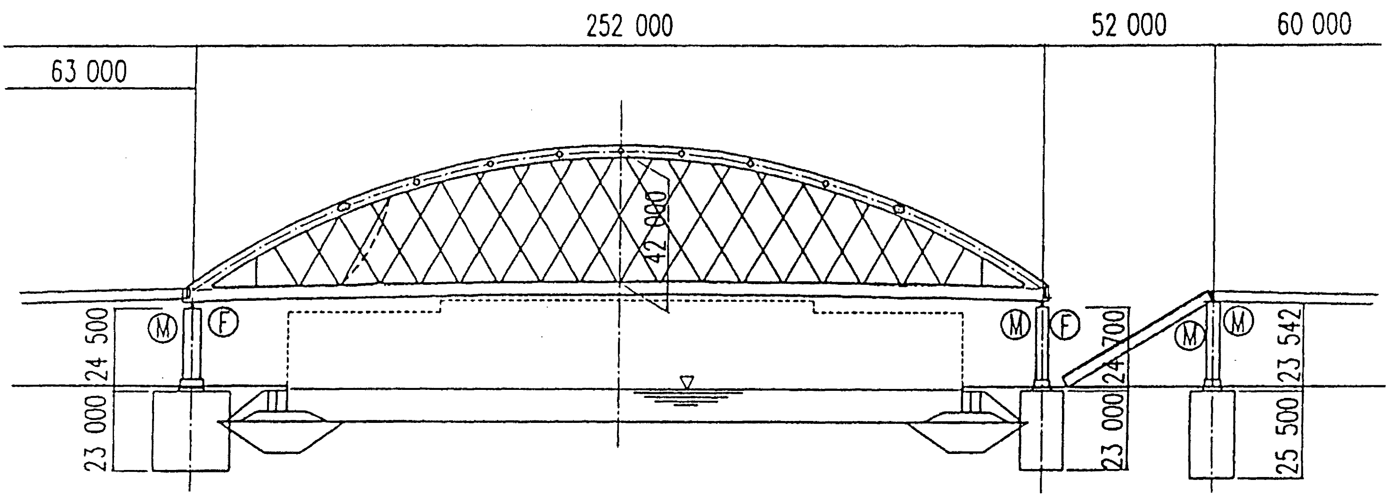


FIGURE 7.6 Nishinomiya-ko Bridge

To reduce the risk of caisson movements in future earthquakes, the reclaimed ground around the eastern pier of the Nishinomiya-ko Bridge is being improved using sand compaction rigs.

The Rokko Island Bridge is illustrated in Figure 7.7. The double decked bridge moved 3.1 m transversely at pier P214 during the earthquake falling about a metre at the same time. The bridge was seriously damaged and required major repairs. The 217m span was lifted back into position using two floating cranes of 4100 t and 3500 t capacity respectively. Refer Figure 7.8. The bridge is expected to reopen on October 31 1995.

HPEC have no major construction or design resources and all the work was carried out under contract.

7.1.4 *Restoration of Kobe Route Expressway*

This elevated expressway suffered extensive damage in the earthquake as noted above and described in section 7.2.1 of Park et al [1995]. A spectacular collapse occurred to a 600m section near Ashiya (Figure 7.2 of Park et al [1995]). Many piers were seriously damaged - refer to 7.3 below. The expressway is not expected to be fully operational again until the end of 1996. The route is being restored in stages as set out in Figure 7.9. The first stage, Maya to Kyobashi is scheduled to open in spring (March) 1996. This will allow traffic better access the Kobe business and port areas by using (a) the restored Kobe Route between Kyobashi and Maya, (b) the on grade Rinkou Route to Ouzaki-hama and (c) the Wangan route on the Osaka and beyond. Figure 7.9, also shows the other stages leading to completion at the end of 1996.

The design principles and philosophy for the restoration work are set out in Table 7.1 above. Comments are as follows:

Foundations. In general, little damage was suffered to foundations. A number of columns, when exposed below ground level, were found to have suffered flexural failures.

Reinforced Concrete Piers. Repairs to damaged piers includes epoxy injection, removal of damaged reinforcement and replacement by lap welding in new bars and reconcreting. In addition, reinforcement of the piers to meet the Ministry of Constructions "Guide Restoration Specification" (refer to section 7.3 below) is being carried out. This includes (a) encasement with reinforced concrete typically 300 mm thick, (b) addition of steel plate encasement as part of (a) in many cases and, (c) steel jacketing or carbon fibre wrapping to reinforce piers for which concrete encasement is not deemed necessary but which have vulnerabilities requiring reinforcement.

Steel Piers. Owing to the post-elastic backing of the steel piers (and collapse of a number of them) concrete infilling is generally being applied as part of the restoration procedure.

Superstructures. Much of the Kobe Route comprises steel I-girders connected with seismic restrainers and supported on rigid or sliding metallic bearings. The restrainers, road joints and bearings were seriously damaged. Restoration work includes making very strong girder connections, eliminating the moving road joints and where appropriate installing elastomeric base isolation support bearings. For all replacement superstructures continuous steel girders will be used because of their good performance in the Great Hanshin Quake.

An item of particular importance in the restoration of this expressway is the environmental standard to be used for the reconstruction. There is considerable pressure to apply much higher standards to the restored expressway and the national highway (Route 43) beneath it than applied before the earthquake. Measures which are being considered include additional noise barriers and the use of porous pavement to mitigate noise. In addition there is a possibility Route 43 may lose two lanes. These matters are illustrated in Figure 7.2.

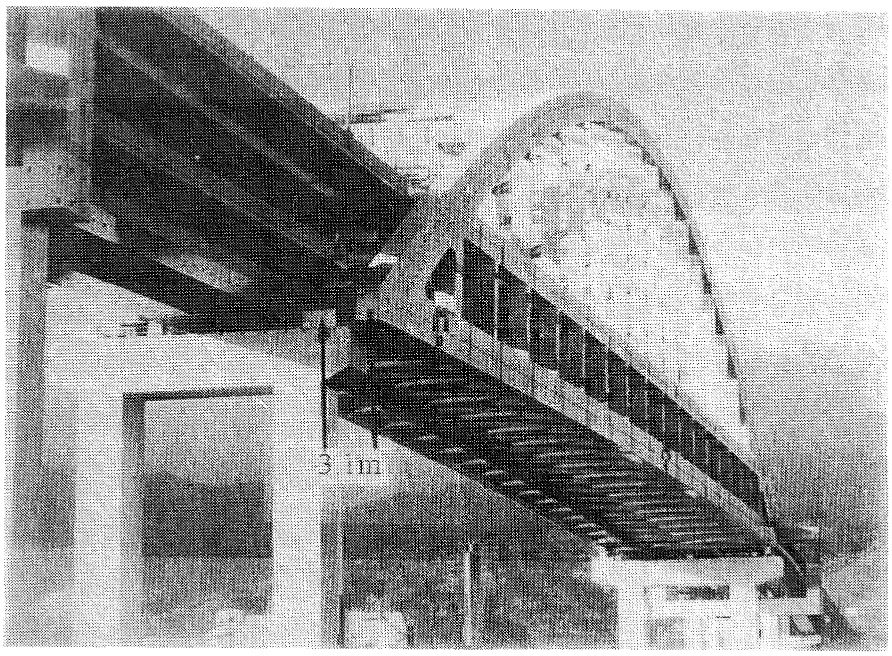


FIGURE 7.7 Damage to Rokko Island Bridge 3.1 m Superstructure Shift

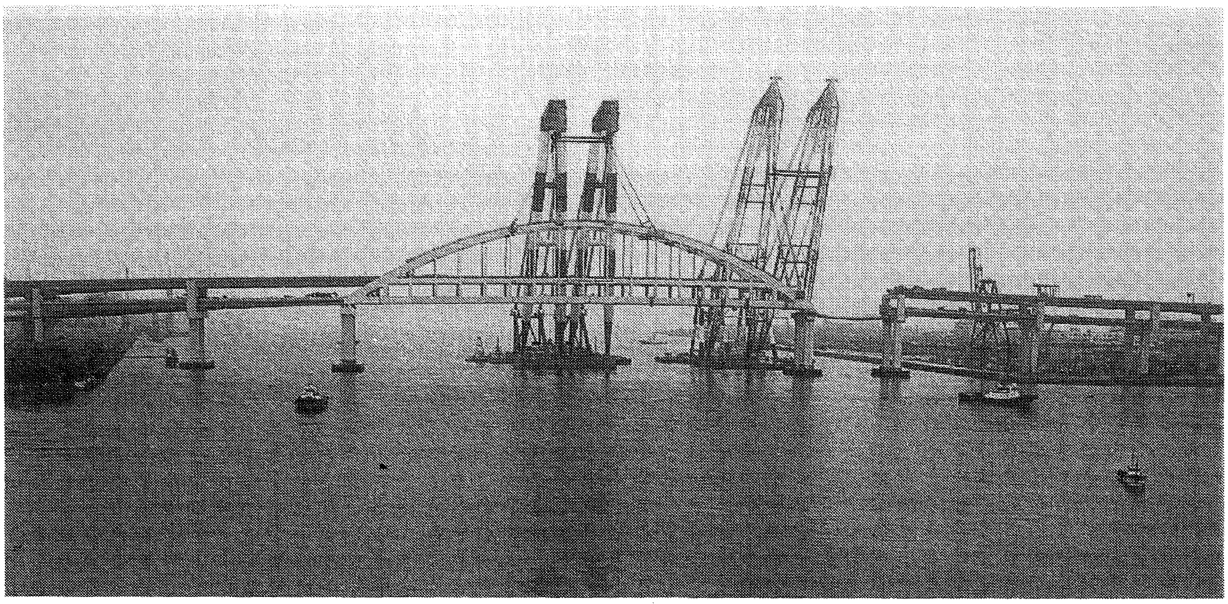


FIGURE 7.8 Rokko Island Bridge Shifting Superstructure back into place

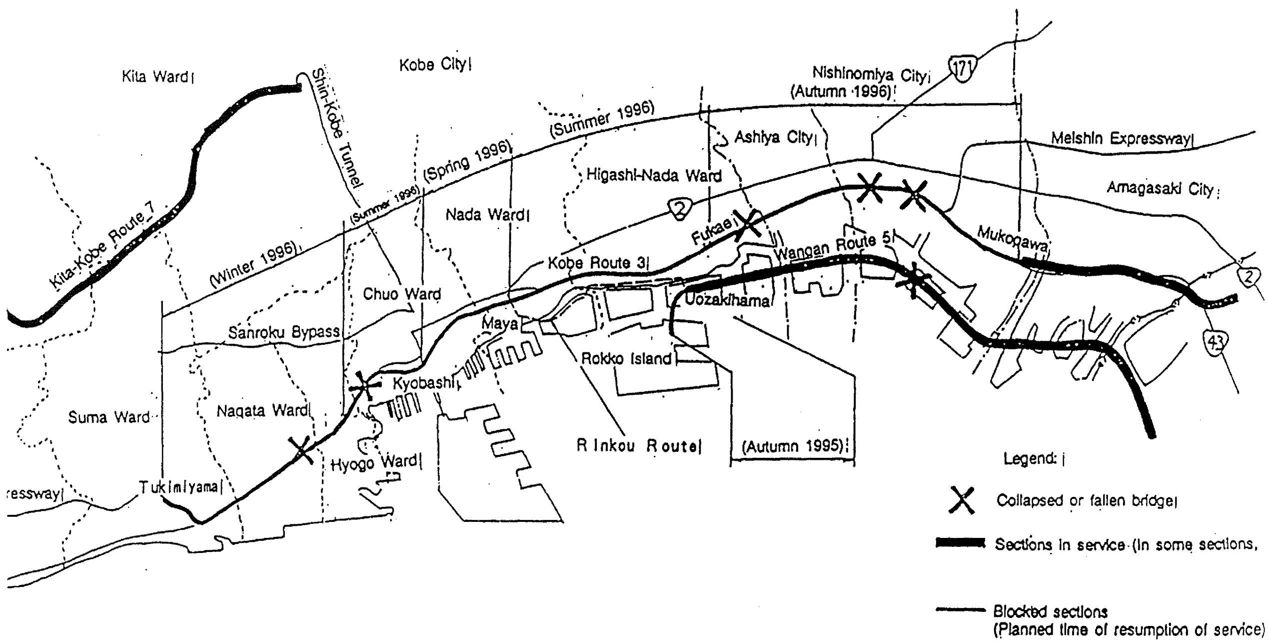


FIGURE 7.9 Restoration Plan for Kobe Route and Wangan Route Expressways (As at July 1995)

7.1.5 *Costs*

The cost of restoration work to the 13 routes of the HPEC including emergency work and restoration of the damaged sections to the standards described above is estimated at NZ$4.4 billion.

HPEC have surveyed all their 13 routes in the Osaka/Kobe area against the Ministry of Construction's latest seismic retrofit standards and estimate the retrofitting cost for urgent seismic retrofit work as a further NZ$3.2 billion.

The "historical cost" value of the HEPC network is NZ$21 billion.

7.2 Japan Highway Public Corporation (JH)

7.2.1 *General*

The Meishin and Chugoken Expressways for which JH is responsible suffered severe damage in the earthquake. Both of these expressways were designed to the 1964 or older Highway Bridge Design Standards [Kawashima, 1995] and had concrete piers and columns with non-ductile details and shear vulnerabilities.

The 20 km section of the Meishin Expressway in the earthquake damage zone is an important link from the Nishinomiya/Kobe area (via the Kobe Route Expressway) to the north and east. It was severely damaged over the 7 km section nearest Nishinomiya and suffered shear failures to the columns with the continuous superstructure sections dropping up to 700mm at some pier locations.

The Chugoken Expressway is a primary highway route which traverses east/west just north of the Kobe/Nishinomiya area. Damage primarily to the bridge piers rendered the route unsafe to traffic. Closure of the route was significant because of the loss of the Kobe Route & Wangan Route Expressways just to the south.

As with HPEC, JH were faced with the urgent need to reopen the facilities to traffic. A restoration policy document was prepared at an early stage. The restoration work comprised three stages.

1. Emergency work to secure the structures and provide safety.

2. Temporary repairs to reopen the routes to traffic.

3. Final repairs.

Temporary repairs were generally carried out in stages, firstly allowing emergency vehicles only, then light traffic and then full traffic.

7.2.2 *Restoration of the Meishin Expressway*

The 4 lane expressway has two separate viaduct structures each supporting two lanes. The superstructure is a reinforced concrete hollow slab continuous over 5 spans, and supported on reinforced concrete wall type piers (Figure 7.10).

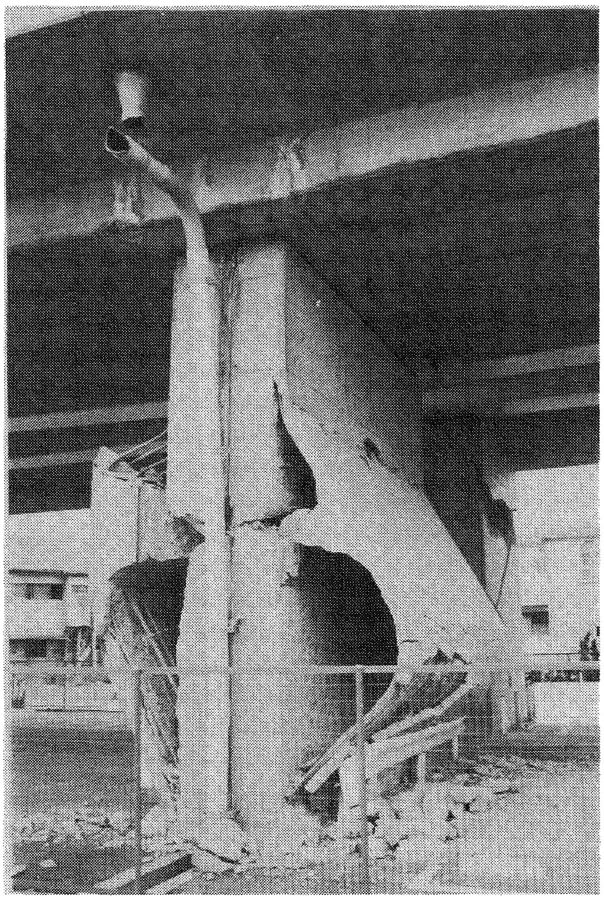


FIGURE 7.10 Meishin Expressway Pier Damage

Damage to the expressway included one span collapse and damage to 457 of the 1,588 bridge piers on the damaged section of the expressway. 99 of the piers suffered spalling or severe damage to the concrete and in the worst cases shear failures and partial collapses of the continuous superstructure (refer to Figure 7.7 of Park et al [1995]). 1,594 of the 3,439 bearings were damaged.

Emergency works allowed the expressway to be opened to one lane of emergency traffic on 2 February. Temporary repair works enabled two thirds of the expressway to reopen on 17 February. The most critical but seriously damaged 7 km section nearest Nishinomiya was finally restored and the whole expressway opened on 31 July 1995.

Temporary repairs were primarily to the concrete bridge piers and the bearings (metallic). The foundations were generally undamaged. Repairs were carried out as follows:

For severely damaged piers requiring reconstruction (Categories A and B on Figure 7.11). the superstructure was supported, jacked back to position if necessary, the column broken out, the reinforcing straightened, new reinforcing comprising D32 longitudinal bars was connected to the existing bars and ϕ 22 ties placed at 150 mm centres at the base and 300 mm elsewhere. Finally concrete was placed. The reinforcement is designed to prevent the flexural/shear failures experienced in the recent earthquake. 97 piers were repaired this way.

For less severely damaged piers repairs were as follows (Figure 7.11).

Category C Epoxy injection and reinforced concrete overlay and steel plate encasement (29 piers).

Category D Steel plate encasement locally on damaged area (17 piers)

Category E Epoxy injection (279 piers).

The restoration work includes changing the metallic bearings at the top of each pier to elastomeric base isolation bearings.

Final repairs to the piers will be carried out over the next two years and will bring the seismic standard up to the "Guide Restoration Specification". These repairs primarily include concrete overlays each side of the piers and additional piles (Figure 7.11).

Damaged superstructure sections were repaired by epoxy injection followed by external steel plate reinforcement (Figure 7.12).

7.2.3 *Costs*

The estimated cost of the restoration work to the JH expressways is estimated as NZ$1.7 billion.

7.3 Design Standards for Highway Bridge Restoration

The design standards used for the restoration of the highway bridges are set out in Kawashima [1995]. After the earthquake the Ministry of Construction formed the "Committee for Investigation of Damage to Highway Bridges in the Hyogo-ken Nanbu Earthquake". This committee, chaired by Dr Iwasaki approved the "Guide Specifications for Reconstruction and Repair of Highway Bridges Damaged in the Hyogo-ken Nanbu

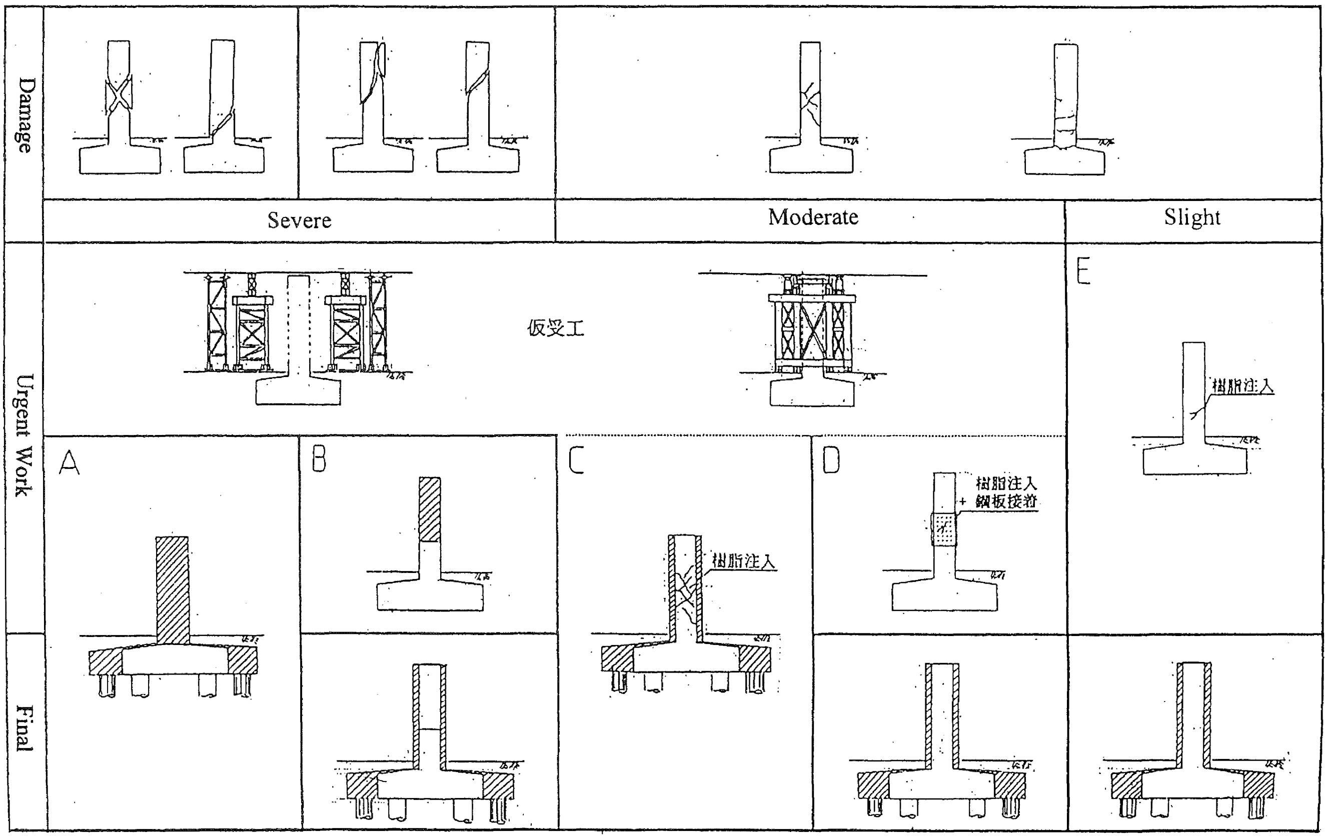


FIGURE 7.11 Meishin Expressway Pier Restoration

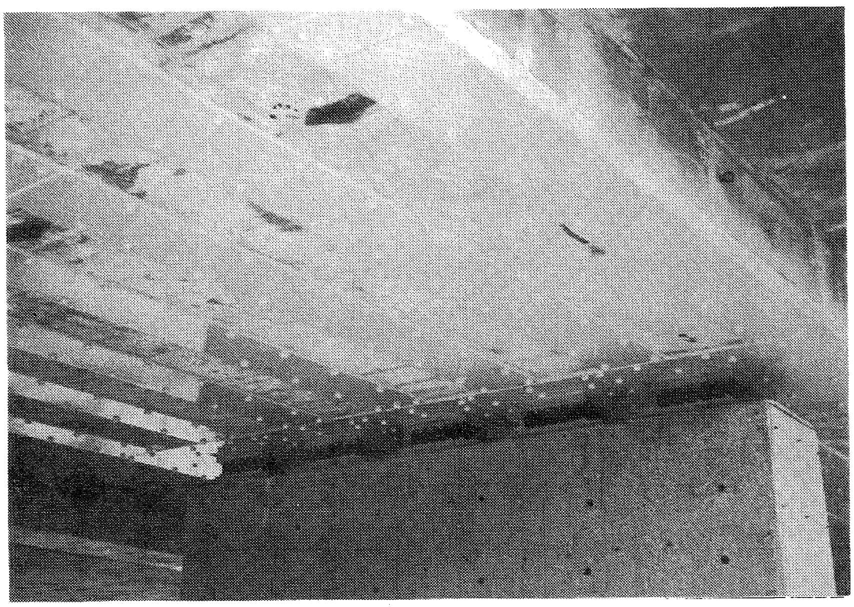


FIGURE 7.12 Meishin Expressway External Plate Reinforcement

Earthquake" on 27 February 1995. This document is referred to as the "Guide Restoration Specification" in this paper. The design standards for highway bridges in Japan are summarised in Table 7.2 of Park et al [1995].

Major changes were introduced to the standard in 1980 and again in 1990. In order to decide on modifications to the 1990 standard for the restoration work it was necessary to study the intensity of shaking in the Great Hanshin Earthquake and the resultant damage.

Of particular interest were the bridges designed to modern seismic standards. The most significant were those of the HPEC Wangan Route Expressway, which was designed to the 1980 and 1990 specifications.

The relative performance of bridges designed to modern codes was made by comparing the Wangan Route Expressway bridges with other bridges. A comparison of the piers with the Kobe Route Bridges, designed to the 1964 and 1971 standards is given below:-

PIER TYPE	DAMAGE CLASSIFICATIONS					TOTAL
	AS	A	B	C	D	
1. Kobe Route						
Steel	3	8	12	112	28	163
Reinforced Conc	65	84	107	246	510	1,012
2. Wangan Route						
Steel	-	-	13	21	109	143
Reinforced Conc	-	-	1	22	200	223

The damage classifications used were:-

AS - Collapse. Extensive damage and loss of capacity.

A - Extensive cracks. Rupture and major buckling of main reinforcement.

B - Local buckling of main reinforcement and large cracks. Local buckling of webs and flanges.

C - Loss of cover concrete and small cracks. Residual deformation of web and flanges.

D - Minor Damage.

It can readily be seen that the bridges designed to modern standards had a far superior performance to the older structures. Similar studies were carried out for the other components. The main conclusions of the studies by the "Committee for Investigation to Damage to Highway Bridges in the Hyogo-ken Nanbu Earthquake" were:

1) Recorded ground motions were much larger than levels anticipated in the design.

2) Many concrete piers failed in shear because of longitudinal steel terminated prematurely. This problem was first addressed in the 1980 standard.

3) Collapse of rectangular steel piers was caused by local buckling of web and flange plates causing rupture of welds.

4) Extensive damage of metal bearings. Few rubber bearings were damaged.

5) Liquification occurred in gravel layers where the potential was previously considered small. Lateral spreading associated with liquification developed.

Using these studies as a basis the "Guide Restoration Specification" for the restoration work were prepared. The Guide Restoration Specification gives additional requirements to the current 1990 bridge standard.

The Great Hanshin Earthquake was characterised by very high ground accelerations and velocities occurring on the softer sites due to ground amplification effects. Typical acceleration response spectra are given in Fig 7.13. As a result the "Guide Restoration Specifications" are currently based achieving adequate performance for peak response accelerations of 1.5g for soft sites, 1.75g for intermediate sites and 2.0g for hard ground sites. While the design seismic lateral force requirements are the same as the 1990 standard, the structures are required to have sufficient ductility to meet the above, acceleration levels.

Key items in the Guide Restoration Specification are:

1) The strength and ductility checks of all seismic carrying members are required including foundations and steel piers (which were previously exempt). Foundations are required to be stronger than piers.

2) Seismic performance for earthquake shaking to the Great Hanshin Quake to be verified by carrying out non-linear time-history analyses. The Kobe marine observatory record is currently being used as input for stiff soil sites (see Figure 7.13).

3) For appropriate (i.e. not soft ground) sites use base-isolation with elastomeric bearings between the superstructure and substructure.

4) Provide sufficient the steel in concrete piers to meet ductility requirements. Minimum tie diameter of 13mm and maximum spacing of 150 mm are required.

5) Steel piers to be concrete filled to ensure they have sufficient ductility.

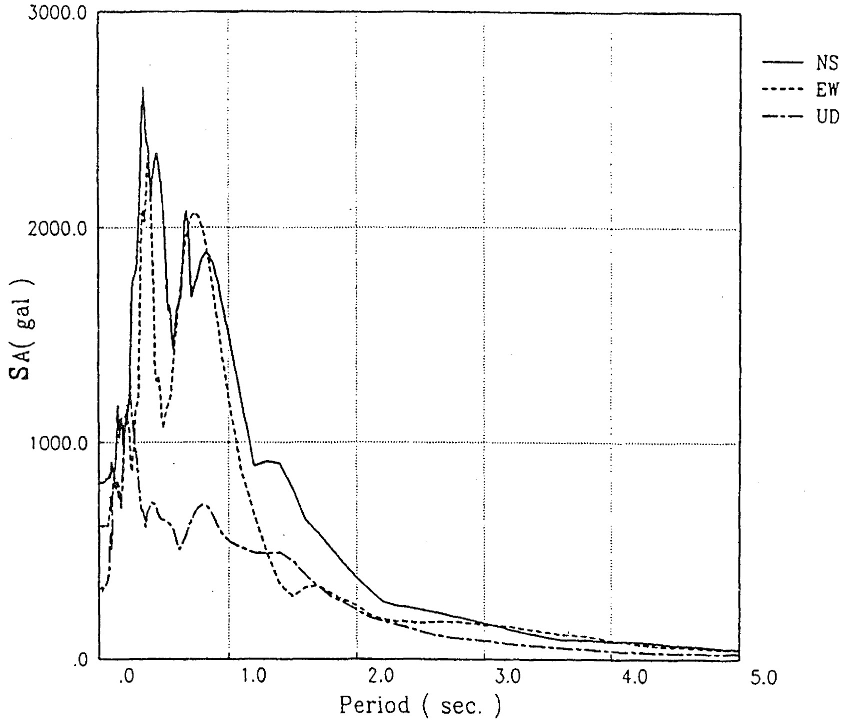
6) Provide both adequate seat length and restrainers to prevent loss of spans.

7) Allow as far as possible, for lateral spreading effects caused by liquification

The above Guidelines only apply to the structures being restored following the Great Hanshin Earthquake. The Guidelines are currently being reviewed for issue as a Japanese bridge standard and will be issued next year. A key item under review is the acceleration response level. It is thought the values noted maybe too high based on observed damage in other earthquakes.

7.4 Retrofitting

A major retrofitting programme for Japanese highway bridges was initiated in 1971 and several tens of thousands of bridges have been retrofitted (see Table 7.1 of Park et al [1995]). In the Kobe area the 600 m section of the HPEC Kobe Route Expressway which collapsed spectacularly was due to be retrofitted within the next 3 years. It was unlucky this was not assigned a higher priority.



(h=5%)
Acceleration response spectra at Kobe marine observatory

FIGURE 7.13 Response Spectra

Table 8.1 Traffic Flows at Ashiya/Nishinomiya City Boundary

	Before Earthquake	15 February 1995	19 April 1995
Kobe Expressway	101,900	0	0
Wangan Expressway	28,300	0	10,800
Route 43 (On grade)	84,000	30,500	41,100
Route 2 (On grade)	38,600	44,000	48,100
Total	252,800	74,200	100,000
Percent of Original		30%	40%

It is now hoped to complete retrofitting of the known vulnerable bridges on Japanese expressways and national highways over the next 3 to 4 years. This is estimated to cost in the order of NZ$2.5 billion.

HPEC have surveyed their installations and as set out in section 7.1 above a cost of NZ$3.2 billion is estimated for this work.

8 EFFECT ON TRAFFIC FLOW

The earthquake resulted in all the primary elevated transportation links between Nishinomiya City and Kobe City being cut, and the remaining on grade highways being chaotically overloaded. The primary road and rail transportation links are shown in Figure 3.1.

The two on-grade highways, National Highway Routes 2 and 43, were the only remaining major east west routes. Because of collapsed and dangerous buildings and bridges, sections of these routes were not passable until demolition and emergency securing had taken place. In addition, the necessary priority for emergency traffic was given by providing emergency lanes on these routes. Further details on the traffic conditions immediately following the earthquake are given in Section 4.2 of Park et al [1995].

The impact of the earthquake on traffic flows between Osaka and Kobe can readily be seen from the traffic flow data for a section surveyed at the Ahiya/Nishinomiya City Boundary as set out in Table 8.1. This section suffered the most severe reduction and traffic flows at mid-February were only 30% of pre earthquake values due to loss of road capacity.

From these data the urgent need for the Hanshin Public Expressway Corporation (HPEC) to reopen the Kobe Route and Wangan Route Expressways can clearly be seen.

The measures taken and strategy adopted by HPEC to achieve this are outlined in Section 7.1 above.

The highest priorities for HPEC were (a) to secure the heavily damaged Kobe Expressway which runs over route 43 (Figure 7.2) thus maximising flows on Route 43 and (b) restoring the Wangan Route Expressway. The traffic flows given in Table 8.1 for the 19 April were taken after the reopening of the Wangan Route on 10 April, and reflect the success of the strategy.

The next priority is reopening the heavily damaged Kobe route expressway in stages which maximise the traffic flows through the critical areas. This strategy is shown in Figure 7.9. The expected traffic flows for the various stages of the restoration are set out in Table 8.2 below, which gives traffic flows at a section just west of the Ashiya/Nishinomiya City Boundary data given in Table 8.1.

Travel times and travel speeds were seriously affected by the earthquake. During the emergency period, immediately after the earthquake road transportation was impractical for vehicles other than emergency vehicles.

Travel distances, times and speeds before and after the earthquake for the Kobe to Osaka section are given in Table 8.3 below.

The time costs of traffic delays have been estimated by the highway authorities to be NZ$3.2 million per day, in April 1995.

Table 8.2 Traffic Conditions at Higashinada/Nada Ward Boundary

	Traffic Volume and Capacity				
Route	Before the earthquake (September 1994)	After the earthquake (March 1995)	Part of the Harbour Highway in service (Autumn 1995)	After restoration of Kobe Route (Fukae-Maya) (Summer 1996)	After Restoration of the entire Kobe Route (Winter 1996)
Route 2	33,000 (4) [34,000]	36,000 (4) [34,000]	(4) [34,000]	(4) [34,000]	(4) [34,000]
Route 43	78,000 (8) [57,000]	38,200 (4) [29,000]	(4) [29,000]	(4) [29,000]	(8) [57,000]
Yamate Route	24,500 (4) [24,000]	34,400 (4) [24,000]	(4) [24,000]	7(4) [24,000]	(4) [24,000]
Hanshin Expressway Kobe Route	115,000 (4) [85,000]	(0) [0]	(0) [0]	(4) [85,000]	(4) [85,000]
Harbor Highway	39,500 (4) [85,000]	(0) [0]	(4) [46,000]	(4) [46,000]	(4) [46,000]
Total	290,600 (24) [246,000]	108,600 (12) [87,000]	(16) [133,000]	(20) [218,000]	(24) [246,000]

- Upper line in each column box: traffic volume (vehicles/day)
- Lower line in each column box: ( ) number of lanes, [ ] traffic capacity (vehicles/day)

Table 8.3 Travel Time/Speed Kobe to Osaka
Eastward travel at 8 am (unless noted)

	Before Earthquake 13 April 1994	After Earthquake 19 April 1995	Ratio
Distance Travel time Average Speed	34.8 km 33 min 62.7 km/hr	35.4 km 2 hrs 4 min 17.1 km/hr	 3.39 0.30
Other eastward travel times	5pm 11pm	2 hrs 1 min 56 min	

Note - Westward travel times similar to Eastward.

9 CONCLUSION

The restoration of the road and rail transportation following the Great Hanshin earthquake has proceeded rapidly with most of the key rail and road links being restored over a period of 3 to 6 months. This is a major achievement involving the expenditure in the order of NZ$10 billion. The resources mobilised for this work were very significant and the restoration of the links in such a short time is a tribute to those involved. The ability to draw on major resources from outside the area was a key factor.

The earthquake has demonstrated the vulnerability of elevated transportation structures which do not meet modern seismic standards. For the highway structures in Japan this has highlighted the need to proceed as fast as possible with the retrofitting programme for seismic mitigation which was started in 1971. For the rail structures the serious vulnerabilities highlighted are of major concern and this has resulted in a major retrofitting programme. The protection afforded by the "capacity design" procedures used for ductile design in NZ are obvious and this appears to be becoming more explicit in the design requirements for the restoration work.

Design standards for the restoration work had to be developed and applied within a few days of the earthquake. Most owners wanted their facilities to be restored to "remain serviceable in shaking equivalent to another Great Hanshin Earthquake". This philosophy has been applied to much of the restoration work. Because of environmental pressures the reconstruction of older structures may need to include additional measures such as noise barriers etc. The potential additional cost and reduction in capacity of highways as a result can be significant.

10 LESSONS FOR NEW ZEALAND

- Transportation routes with elevated structures or crossing liquefiable ground are vulnerable to earthquake shaking, even in areas of moderate seismicity.
- Retrofitting of transportation lifeline routes in the main cities should proceed and major vulnerabilities should be mitigated as soon as possible.
- Standards for retrofitting should be established and applied.
- Provision should be made for mobilize resources for emergency works from outside each main city.
- Roading authorities should plan for emergency access requirements in the emergency and restoration period after an earthquake (having identified applicable vulnerabilities).
- Restoration of heavily damaged elevated structures can be expected to take several months.
- Environmental considerations are likely to mean that where reconstruction work is required, the original design standards and requirements may not be applicable.

ACKNOWLEDGEMENTS

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