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Technical Note of PWRI No.４２８７

CURRENT PRACTICE OF REPAIR AND RESTORATION TECHNOLOGY FOR BRIDGES DAMAGED BY EARTHQUAKES

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CURRENT PRACTICE OF REPAIR AND RESTORATION TECHNOLOGY FOR BRIDGES DAMAGED BY EARTHQUAKES

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Synopsis :

This volume compiles the current practice of repair and restoration technology for bridges damaged by the earthquakes. The technology was compiled based on the past earthquake damage experiences in Japan. It presents the temporary repair and permanent repair methods for damaged bridges, as well as basic concept for repair and restoration. Evaluation methods of damage degree and several repair methods dependent on the damage degree are presented.

This volume is the English translation of the part of "Manual for Earthquake Disaster Countermeasures for Roads, Post Earthquake Recovery, Japan Road Association (2007)." The translation was made with the official approval of the Japan Road Association.

Key Words: Highway Bridge, Earthquake, Damage, Inspection, Repair

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1. INTRODUCTION

Since highway network service is one of critical infrastructures for human lives and economical activities, earthquake damages to highway network significantly affect them as well as the rescue activities and restoration works. Furthermore, damage to highway will extend the affected area widely. Particularly, once intensive damage occurs in the area with trunk highway, significant effect will be expanded due to the unavailability of the transportation system. Therefore, when an earthquake occurs, it is essential to understand the damage and to repair that as soon as possible.

This volume compiles the current practice of repair and restoration technology for bridges damaged by the earthquakes. The technology was compiled based on the past earthquake damage experiences in Japan. It presents the temporary repair and permanent repair methods for damaged bridges, as well as the basic concept for repair and restoration. Evaluation methods of damage degree and several repair methods dependent on the damage degree are presented.

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2. PLANNING OF REPAIR AND RESTRATION

2.1 Process of Repair and Restoration

Damage of road function due to an earthquake may cause not only the prevention of the repair and restoration activities in the damaged area, but also significant effect on civil lives and economic activities in and around the damaged area. Consequently, the repair and restoration of damaged road facilities should be conducted immediately by grasping the damage in a prompt and appropriate manner and by communicating with the related organizations and authorities based on the emergency management plan.

Repair and restoration of road facilities after an earthquake can be classified into three stages as shown in **Figure 2.1.1**. It should be noted that the presented in this figure is a general process of repair and restoration works and it may vary according to the affected area and damage degree.

(1) First Stage of Repair and Restoration (Emergency Inspection and Emergency Measures)

The first stage of repair and restoration is a stage in which emergency inspection is carried out to grasp an overview of damage and critical damage, and emergency measures such as traffic control and preventing the expansion of damage are taken. Emergency measures are also needed for the structures which is likely to collapse.

(2) Second Stage of Repair and Restoration (Inspection for Temporary Repair, Temporary Repair and Restoration, and Draft Planning of Permanent Repair and Restoration)

In the second stage of repair and restoration, damage to road facilities is comprehensively inspected, and temporary measures are taken to prevent the secondary disasters according to the state of damage progress. Temporary repair and restoration are also conducted based on the urgency for ensuring road traffic function, and the plan for permanent repair and restoration is drafted in accordance with the importance of road, damage degree of structures, and difficulty of repair and restoration.

(3) Third Stage of Repair and Restoration (Inspection for Permanent Repair and Restoration, and Permanent Repair and Restoration)

The third stage of repair and restoration is a stage to develop a plan for permanent repair and restoration based on detailed inspection results of damage to road structures, and to conduct the permanent repair and restoration works to ensure the required seismic performance level of road facilities based on the restoration plan.

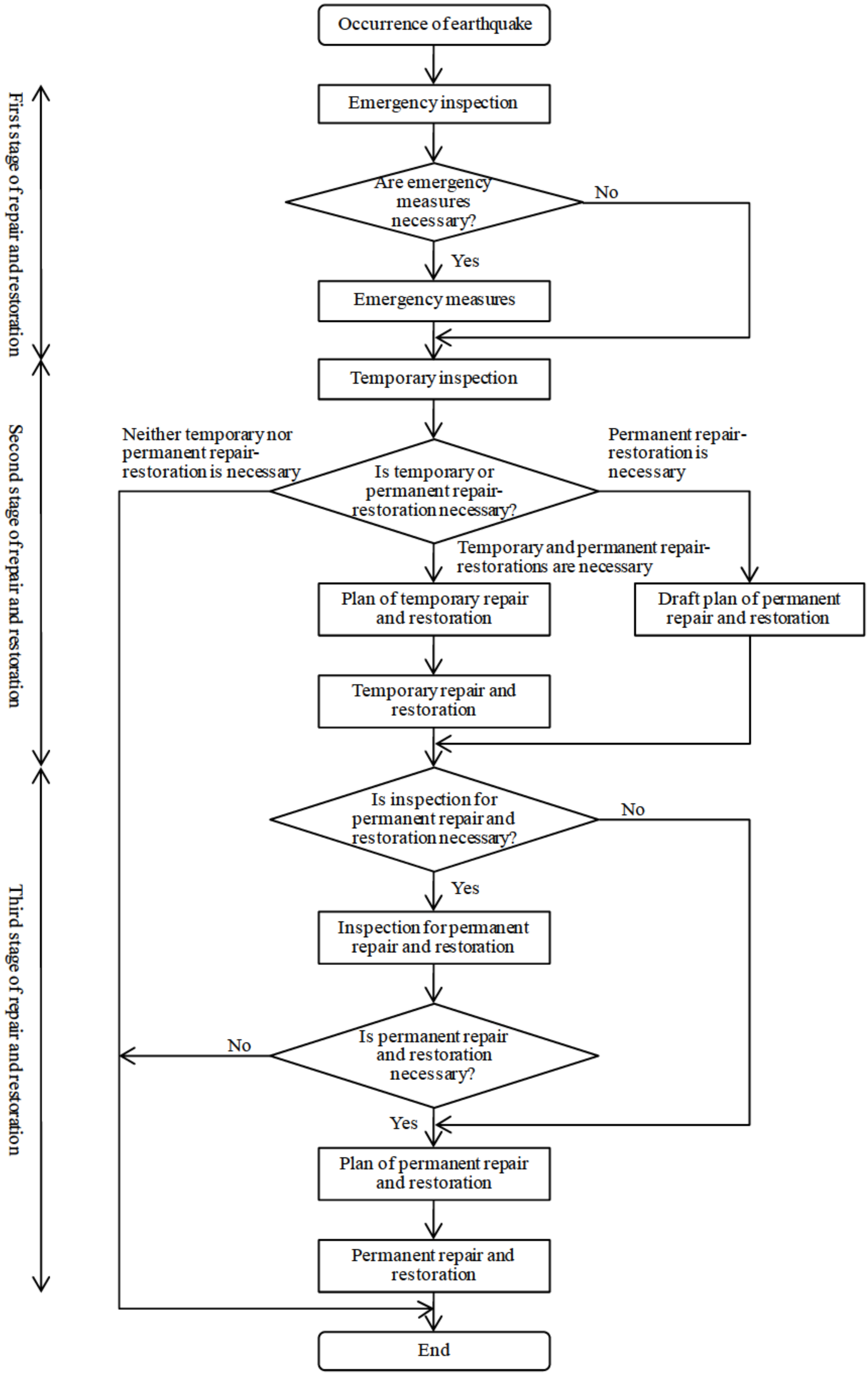


Figure 2.1.1 General Procedure of Repair and Restoration

2.2 Factors to be considered in Repair and Restoration

(1) First Stage of Repair and Restoration (Emergency Inspection and Emergency Measures)

In the first stage of repair and restoration, it is important to grasp an overview of damage to road facilities promptly and to take adequate emergency measures to prevent the occurrence of secondary disasters. There exist little choices of priority regarding repair and restoration in the first stage, which is different from the second and third stages of repair and restoration. Most of the evaluation factors in the first stage are those to examine the risk of secondary disaster occurrence and its influence. The general factors to be considered in the emergency inspection and measures are as follows:

1) Characteristics of main shock, aftershocks, tsunamis and weather conditions
2) Characteristics of damaged area
   - Urban city or local city
   - Mountain, plain or coastal area
3) Risk of secondary disaster occurrence
   - Risk of damage spreading
   - Influence of damage to road facilities on nearby residents and other facilities, and the spreading risk of damage influence
4) Relationship with facilities managed by other organizations or authorities
   - Influence of damage to other facilities over roads, and the spreading risk of damage influence

A railroad viaduct crossing a major highway in Kobe City was unseated in the 1995 Hyogo-ken-nanbu Earthquake. The road administrator constructed temporary supports for the railroad viaduct and removed the girders as emergency measures, because it was required to reopen the road for the transportation of the emergency goods shortly.

Among the above-mentioned factors, the risk of secondary disaster occurrence is important in the first stage of repair and restoration, especially the discovery of damage that may cause fatalities and the adequate measures are of great importance in the first stage. It is noted that how much risk of secondary disaster should be coped with in the first stage varies dependent on the degree of earthquake disaster and the extent.

After the disasters occur, various secondary influences resulting from them are expected to occur. **Table 2.2.1** shows types of the secondary influences on road facilities. They are roughly classified into the case with expansion of primary disasters and that without expansion of primary disasters. Furthermore, they are ramified into five types, where the Types A, B and D are recognized as the secondary disasters. The Types C and E are influences resulting from malfunction of road traffic function. It is noted that the expansion of damage to road facilities (Type A) includes the damage of road facility induced by the damage of roadside facilities, in addition to the damage expanded by aftershocks or rainfalls.

Table 2.2.1 Classification of Secondary Influences accompanying Primary Disasters

<table>
<tr><th colspan="2">Types of Secondary Influences accompanying Primary Disasters</th><th>Damage Description</th><th>Remarks</th></tr>
<tr><td rowspan="3">Case with expansion of primary disasters</td><td>Type A
New damage to road facilities including one induced by damage to other facilities</td><td>1. Progress of damage of bridge → Falling off of girder
2. Progress of cracks on slope → Collapse of slope
3. Progress of cracks on tunnel lining → Roof-fall of tunnel
4. Progress of damage to sewer pipe → Subsidence of road surface</td><td>Risk of secondary disasters</td></tr>
<tr><td>Type B
New disasters accompanying Type A</td><td>1. Falling off of girder → Fall of passing vehicles, damage to road, railroad, etc. under the bridge
2. Collapse of slope → Burying roadside houses, damage to human lives and properties
3. Roof-fall of tunnel and subsidence of road surface → traffic accidents</td><td>Risk of secondary disasters</td></tr>
<tr><td>Type C
New influences accompanying Type A excluding Type B</td><td>1. Traffic control and detour → Traffic congestion
2. Decrease of traffic capacity → Influence on civil lives and manufacturing activities
3. Suspension of emergency vehicle passage (ambulance, fire engine) → Influence on human lives and properties</td><td></td></tr>
<tr><td rowspan="2">Case without expansion of primary disasters</td><td>Type D
New disasters accompanying deterioration of road function by primary disasters</td><td>1. Falling off of girder and damage to road surface → traffic accidents
2. Falling rocks and soils on road → traffic accidents
3. Subsidence of road surface → traffic accidents</td><td>Risk of secondary disasters</td></tr>
<tr><td>Type E
New influences accompanying deterioration of road function by primary disasters excluding Type D</td><td>1. Traffic control and detour → Traffic congestion
2. Decrease of traffic volume → Influence on civil lives and manufacturing activities
3. Suspension of emergency vehicle passage (ambulance, fire engine) → Influence on human lives and properties</td><td>Types of damage are same with Type C.</td></tr>
</table>

(2) Second Stage of Repair and Restoration (Temporary Repair and Restoration)

In the temporary repair and restoration, it is important to select sites among various sites damaged simultaneously by an earthquake and how to determine the priority for repair and restoration. The basic factors to be considered to determine the temporary repair and restoration policies are as follows:

1) Damage state and degree
2) Risk of occurrence of secondary influences including secondary disasters resulting from the primary disasters.
3) Degree of secondary influences including secondary disasters resulting from the primary disasters.
4) Restrictive conditions with temporary repair and restoration.

Table 2.2.2 shows the principal evaluation items for the above four factors. It is necessary to comprehensively evaluate the items given in **Table 2.2.2** for determining the priority of temporary repair and restoration. The most fundamental is to prevent secondary disasters, to send relief to the damaged areas or evacuation facilities, and to ensure at least one route to transport emergency goods.

After ensuring necessary routes should be prioritized, demand of emergency goods transportation, degree of damage to the routes or difficulty of repair and restoration, and efficient use of detours and alternative routes should be carefully examined.

In the temporary repair and restoration, there are two stages of ensuring traffics according to damage degree and urgency, in general, as follows:

1) **First stage (Minimum repair and restoration to ensure emergency transportation)**
   In the first stage, the repair and restoration work is made with available machinery and materials to pass vehicles for emergency transportation until the second stage.
2) **Second stage (Temporary repair and restoration to ensure general traffic until the permanent repair and restoration)**
   In the second stage, the repair and restoration including temporary pavement is made to ensure smooth and mass transportation to a certain extent for both emergency and general vehicles.

Table 2.2.2 Evaluation Factors in the Second Stage of Repair and Restoration after Earthquake

Classification	Evaluation Factors
Damage state and degree	• Damage to road facilities • Damage to area • Degree of deterioration of seismic performance of road structures • Stability of damaged section • Degree of influence due to deterioration of road function
Risk of secondary influence occurrence accompanying primary disasters	• Aftershocks, rainfalls, snowfalls, etc. • Human influences such as passage of heavy weight vehicles and traffic volume
Degree of secondary influence occurrence accompanying primary disasters	• Existence of detour or alternative route • Area and population affected by traffic control • Type or volume of traffic and freight transportation affected by traffic control • Influence of deterioration of traffic function accompanying secondary influences
Constraints by beginning of temporary repair and restoration	• Social conditions such as rescue activities and jurisdictional responsibility for repair and restoration • Approach route to damaged area • State of machinery or materials required for repair and restoration • Coordination with the related organizations and authorities
Constraints by completion of temporary repair and restoration	• Conditions to induce secondary disasters such as rainy season or snowfall season • Social conditions such as sightseeing season, local events, etc. • Period of alternative function ensured by emergency measures

(3) Third Stage of Repair and Restoration (Permanent Repair and Restoration)

In the third stage of repair and restoration, confusion after an earthquake has generally subsided and facility functions have been recovered to some extent by temporary repair and restoration. It is therefore important to determine appropriately function and seismic performance level of roads for the permanent repair and restoration, and to perform the permanent repair and restoration, incorporating the future plans of facilities.

The basic factors to be considered to determine the permanent repair and restoration policies are as follows:

1) Coordination with future plans and restoration plans of the affected area including facilities managed by other authorities.
2) Risk of re-occurrence of disasters.
3) Relationship with other facilities.

In the restoration from the 1995 Hyogo-ken-nanbu Earthquake, the repeated restoration works at the same road section by different lifeline organizations impeded the traffic. Close coordination of work process among various organizations is important.

Levels of the permanent repair and restoration can be classified into the following two levels:

1) Recover the functions of facilities as before an earthquake

- Repair and restoration with the same structure and material as before an earthquake

  This aims to repair and restore the damaged facility as before an earthquake. Remove the damaged facility and construct new one if it is less expensive than repair or if the remaining lifetime of the facility is short and the repair is not suitable for long time use.

- Repair and restoration by relocation

  This is applied to a case in which a facility is heavily damaged and the recovery at the original location is difficult.

2) Improve the functions and benefits of facilities

Factors to be considered to improve the seismic performance of facilities are as follows:

- Risk of re-occurrence of disasters (Risk of damage occurrence by future earthquakes)
- Importance of facilities (Important facilities)
- Remaining lifetime of facilities (Facilities with long-remaining lifetime)
- Difficulty of repair (Facilities requiring large-scale repair work with special machinery or materials)
- Number of similar types of damage in the past earthquakes (Types of damage which occurred repeatedly)
- Degree of damage (Facilities with severe and unusual damage)

The following measures are available to improve the seismic performance of facilities, in principle.

- Repair and restoration with same structure and different materials.
- Repair and restoration with different structure and same materials.
- Repair and restoration with different structure and materials.

A general procedure of the permanent repair and restoration is shown in **Figure 2.2.1**.

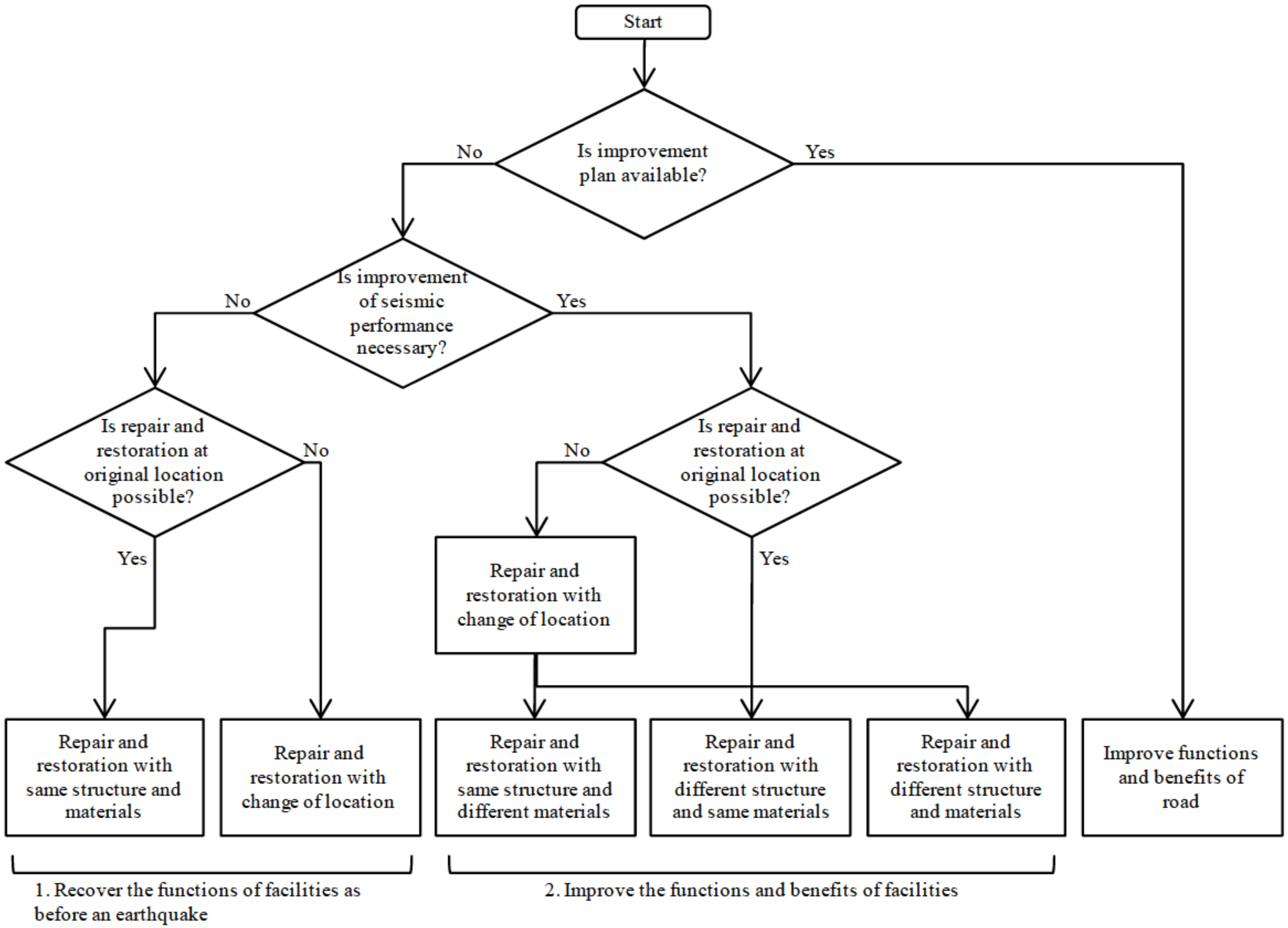


Figure 2.2.1 Levels of Permanent Repair and Restoration

(4) Attention Issues on Whole Earthquake Disaster Restoration

1) Managing Organization for Earthquake Disaster

In the 1995 Hyogo-ken-nanbu Earthquake, it was reported that the establishment of initial emergency response organization was delayed because of the difficulty to gather the first responders as well as connection down within the related organizations. It was recognized again that the response works which are significantly different from the usual have to be conducted promptly under the completely different environment situation during the occurrence of earthquakes.

In case of an earthquake disaster, it is important for the response organizations that every member takes suitable action according to the emergency management plan which is made in advance, and the flexible correspondence to unexpected situations such as rearranging the response organization to be suitable for the earthquake measures is also important.

The attention issues for the response organization are as follows.

a) Check of staff's roles

b) Responsible person is to be at the place which can always be connected.

c) Support to send staffs to the site

d) Establishment of support and cooperative structure with private sectors

e) Hearing of opinions from experts and experienced persons for earthquake disaster restoration

f) Unification of directions, commands and information control

g) Reservation of communication measures immediately after the suffering

h) Staff's health care administration

2) Cooperation with Related Organizations

In the 1995 Hyogo-ken-nanbu Earthquake, the reopening of roads was significantly interrupted by taking time for the removal of neglected vehicles and collapsed houses on the roads. This delay was caused by the interference of the connection between related organizations due to the shutdown of the telephone system. Moreover, it was the problem that the adjustment of construction time was not performed enough for the restoration of lifelines. In performing the disaster investigation, emergency measures, and restoration works after an earthquake, it is necessary to aim at sufficient deliberations and adjustment with the following related organizations on the contents, times, operation methods, etc. in order to promote the restoration work smoothly.

It is necessary to consider the necessary cooperation scheme about the communication method, road reopening, restoration, etc. beforehand with the related organizations.

a) Road administrators

b) Local government (Disaster management office)

c) Police

d) Fire fighting

e) Lifeline entrepreneur (Electric power, telephone communication, water and sewage, gas)

f) Self-defense forces

g) Press (Broadcasting station, newspaper publishing company, etc.)

3) Maintenance of Facility Management Information

In the damage investigation, the determination of damage degree, and the selection of restoration construction methods for damaged infrastructures, the information on infrastructures including the design drawings and specifications, management documents, past inspection records, disaster histories (disaster prevention charts), etc., are necessary for the effective treatment. For example, the damage situation of the part which cannot be checked by the visual inspection can be presumed from the past inspection records. Moreover, if the similar damage occurred repeatedly in the past, it is necessary to consider the earthquake-proof improvement for that.

Therefore, it is desirable to accumulate and manage these pieces of information appropriately daily, and to enable it to use these quickly at the time of an earthquake occurrence.

4) Conduct of Disaster Recovery Project

Procedures such as applications of disaster restoration, disaster assessments, and determination of disaster restoration work expenditures are needed for the recovery works. To conduct the disaster recovery project of the infrastructures administrated by the Ministry of Land, Infrastructure, Transport and Tourism, fixed requirements have to be satisfied (refer to "Law on Disaster Restoration Works Expenditure of Public Infrastructures").

5) Measures against Aftershocks and Rains

After the occurrence of an earthquake, the measures against the landslide disaster by the progress of damage by aftershocks, rains, etc., is needed. The measures include inspection of vulnerable places by experienced engineers, removal of unstable earth and sand, conduct of emergency construction such as installation of temporary safety barriers, information dissemination to related organizations and residents, and suitable warning and evacuation.

Scales, occurrence time terms, and the number of times of aftershocks vary greatly with the earthquake, and are difficult to predict them correctly. Therefore, the earthquake disaster correspondence considering the possibility of aftershocks in mind becomes important. For example, it cannot be mentioned that aftershocks are always weaker than main shock (in the 2003 Miyagi-ken-hokubu Earthquake, the main shock of M 6.4 occurred 7 hours after the earthquake (foreshock) of M5.6). Moreover, although the intensity of aftershocks is an issue for the damage restoration, aftershocks with the intensity comparable as the main shock may occur depending on the location of aftershocks (in the 2004 Niigata-ken-chuetsu Earthquake, JMA (Japan Meteorological Agency) intensity scale of upper 6 was observed 38 minutes after the main shock with JMA intensity scale of lower 6).

Since aftershocks influence seriously the mentality of local residents and the responders engaged in the earthquake disaster restoration works, simultaneously with the expansion of physical damage, it is important to perform the correspondence considering sufficient safety. The matters which should care as measures against aftershocks in the restoration period are shown in the followings.

a) When structural correspondence and measures cannot be taken, designation of vulnerable area, regulation, etc. should be performed.

b) Disaster investigation and restoration work should be performed considering the possibility of damage which was not able to grasp after the main shock and the progress of damage by aftershocks.

c) In the case of disaster investigation or construction, cares to workers' safety should be paid including the preparation of evacuation areas, and interrupting works and checking the surrounding safety when aftershock occurs during the work.

d) When the earthquake with maximum JMA seismic intensity of 5 or more occurs, refer to the information on the announcement from the JMA about aftershocks

6) Attention Issues in Snowy Area

Although there is no example so far, when a large-scale earthquake occurs at a snowy area in a snow season, the following attentions including avalanche and slope collapse are needed to be paid. In addition, not only the investigation immediately after suffering damage but the re-investigation after thaw is also needed.

a) Increase of human and physical damage caused by simultaneous occurrence of avalanche, snow and ice fall from buildings

b) Traffic interruption of emergency transportation roads by collapse of the road side snow walls and flight interruption of helicopters by bad winter weather

c) Delay of restoration caused by the increase of snow-removal work added to emergency rehabilitation work

Moreover, anticipated secondary disaster is the fluidization phenomenon in which earth and sand mixed in the flow of snow and water occurs. This is caused by the sudden collapse of natural dam that is developed by the close-up of rivers by the avalanche in mountain slope and slope collapse. It is necessary in planning of emergency rehabilitation and restoration work to take the possibility of that in a snow season into consideration.

In the 2004 Niigata-ken-chuetsu Earthquake, for the routes other than the routes which are regularly closed in winter season, emergency rehabilitation was performed in about two months from the earthquake occurrence (October 23) to the snow season so that the trouble might not occur for the driving of snow-removal work vehicles. Moreover, the survey which is needed for the design of the restoration work was carried out in parallel to the emergency rehabilitation work.

Since the affected area was hit by the heavy snowfall, road surface subsidence and cave-ins occurred frequently. In this restoration work after thaw, re-implementation of the investigation of the road surface and cavernous was needed. Moreover, examination of the construction process considering the temporary discontinuation of works in the next snow season was performed.

2.3 Emergency Inspection and Emergency Measures (First Stage of Repair and Restoration)

(1) General

In the first stage of repair and restoration, while grasping the outline of damage situation as quick as possible, an emergency measure is performed to the damage which may lead to a serious secondary damage. The appropriate judgment of the outline about the damage situation of managing facilities and the treating measures are focused on.

(2) Emergency Inspection

1) Conduct of Emergency Inspection

For the emergency inspection,

a) As much as possible in a short time

b) The overall outline of damage and trafficability of roads, and the existence of serious damage are to be grasped

c) Then, it is essential to judge sections with the vulnerability of leading to serious secondary damage.

The points of emergency inspection are as follows:

a) Prompt Initiation of Inspection

・The predetermined responsible persons (personnel, contractors) who are in charge of emergency inspection are mobilized promptly (with necessary equipments).

・Check the situation of inspection and dispatch investigators about the section in which the situation is not grasped.

・When personnel cannot be secured because of the earthquake occurrence other than working hours, priority is given to the sections about which the vulnerability is anticipated in daily patrol.

・In order to grasp the broad disaster situation, preparations to dispatch a helicopter is made.

b) Top Priority is given to grasp Overall Disaster Situation

・Do not concentrate into small damage and its treatment more than needed.

・First of all, put emphasis on checking the overall situation.

c) Periodical Report

・Report the investigation results to commander for every time or every point set beforehand.

・Report a serious damage situation immediately after recognition.

The investigation is generally focusing on the items shown in **Table 2.3.1** as well as caring the points for the emergency inspection shown in the above.

In addition, it is the most case where only visual investigation by viewing by the limited staff and in restricted short time is performed for the emergency inspection. It is necessary to investigate carefully whether there is any oversight of emergency inspection by subsequent investigations for temporary repair or permanent restoration.

Table 2.3.1 Main Items for Emergency Inspection of Road Facilities

Road Facilities		Points to be inspected
Road (Flat Road)		Large road surface subsidence, cracks, road obstacles
Cutting Ground and Slope		Large-scale slope failure, large falling stone, large road surface failure
Embankment		Large road surface subsidence, embankment, lateral spreading
Bridge	Whole	Unseating of superstructures
	Bridge Surface	Gap, crease angle, meandering of safety barriers for vehicles and curbs
		Crease angle of vertical section alignment
		Opens and level differences of expansion joints
	Bridge Superstructure	Discontinuous (crease) bending
	Bridge Substructure	Subsidence, inclination, large crack, spalling-off of concrete, deformation and fracture of re-bars
	Bearings	Collapse of bearings, breakage of bolts
	Unseating Prevention Devices	Fracture and deformation
Tunnel		Large collapse at entrances, large failure of lining
Other Road Facilities	Common Utility Ducts	Projection to road surface (patrol from the ground), serious damage of duct structures
	Canal Road	Crack and deformation of retaining walls, floating of structures, springwater leakage and large road surface subsidence
	Retaining Wall	Crack and deformation of retaining walls, crack of upper natural slope ground, springwater leakage
	Rock Shed and Snow Shed	Falling stone, earth-and-sand failure, existence of avalanche, damage of structure, inclination, and large crack
	Pedestrian Bridge	Unseating, serious damage of bridge piers
	Calvert, Underground Pedestrian Crossing	Large road surface subsidence, opening of masonry joints
	Cut and Cover Tunnel	Large failure, large crack, spalling-off of concrete, floating of tunnel, and springwater leakage
Except Road Facilities	Roadside Facilities	Large collapse of buildings on roads Does the damage of road infrastructures influence seriously?
	Occupied Facilities	Does the damage influence the traffic function seriously?
	Others	Large-scale flooding, existence of tsunami, existence of large fires, vehicles conjestion situation

2) Methods of Emergency Inspection

Investigation methods are divided roughly into ground investigation and investigation by the remote sensing from the air. Although the ground inspection is essential, the situations which are difficult to investigate by the ground inspection including the existence of the large road surface cave-in, large-scale slope failure, large-scale flood, tsunami, fire, and traffic situation are investigated from the sky in parallel with the ground investigation. Moreover, for the places where the ground inspection is difficult such as detached islands, the outline of damage is grasped by the investigation from the air.

In addition, the investigation methods discussed here is applied not only to emergency inspection but to the investigation for temporary repair or permanent restoration. The feature and application investigation stage according to investigation methods are shown in **Table 2.3.2**.

Table 2.3.2 Comparison of Investigation Methods

Investigation Methods			Features	Application Stage			
				Before Event	After Event		
					Urgent	Temp-orary	Perm-anent
Ground Investig-ation, etc.	Ground Investigation		Essential investigation method for urgent investigation and conduct as much as possible.		↔		
	Investigation by CCTV Cameras		Urgent investigation method to complement the ground investigation. Effective during the time before the investigation team is not established well. Although limited to the views by cameras, possible to grasps the outline of damage.		↔		
Investig-ation by Remote Sensing from Air	Aerial Photo	View from Helicopter, Video, Photo	Complementary investigation method when the ground investigation is difficult or takes long time.		← 1 or 2	days	
		Interpretation and Measure of Aerial Photo	Investigation method for a wide affected area and for the area where the ground investigation is difficult. Damage situation can be grasped and damage scale can be measured.	↔	→	1 week	
		Detailed Measure of Aerial Photo	Investigation method to obtain data necessary for the development of recovery planning including development of plan and sectional views of damaged area.			→ Till Permanent	Repair
	Laser Scanner		A method to measure necessary for the development of recovery plan in more detail than aerial photo.			→	→
	High Resolution Artificial Satellite		Effective to detect a large scale slope failure. Limited because of the timing of satellite location.		↔		

(3) Emergency Measures

1) Conduct of Emergency Measures

When damage as shown in **Table 2.3.1** is discovered during the emergency inspection, or when there is a possibility of the occurrence of a serious secondary damage, emergency measures are conducted according to the flowchart of **Figure 2.3.1**.

On the other hand, when the damage is comparatively light and has become the hindrance of traffic around the damage section, among the level difference and cave-in of road surface and soil failure on road surface, it is necessary to secure the traffic route by temporary filling in the gap section and cave-in part with sandbags, etc. and by removing soils.

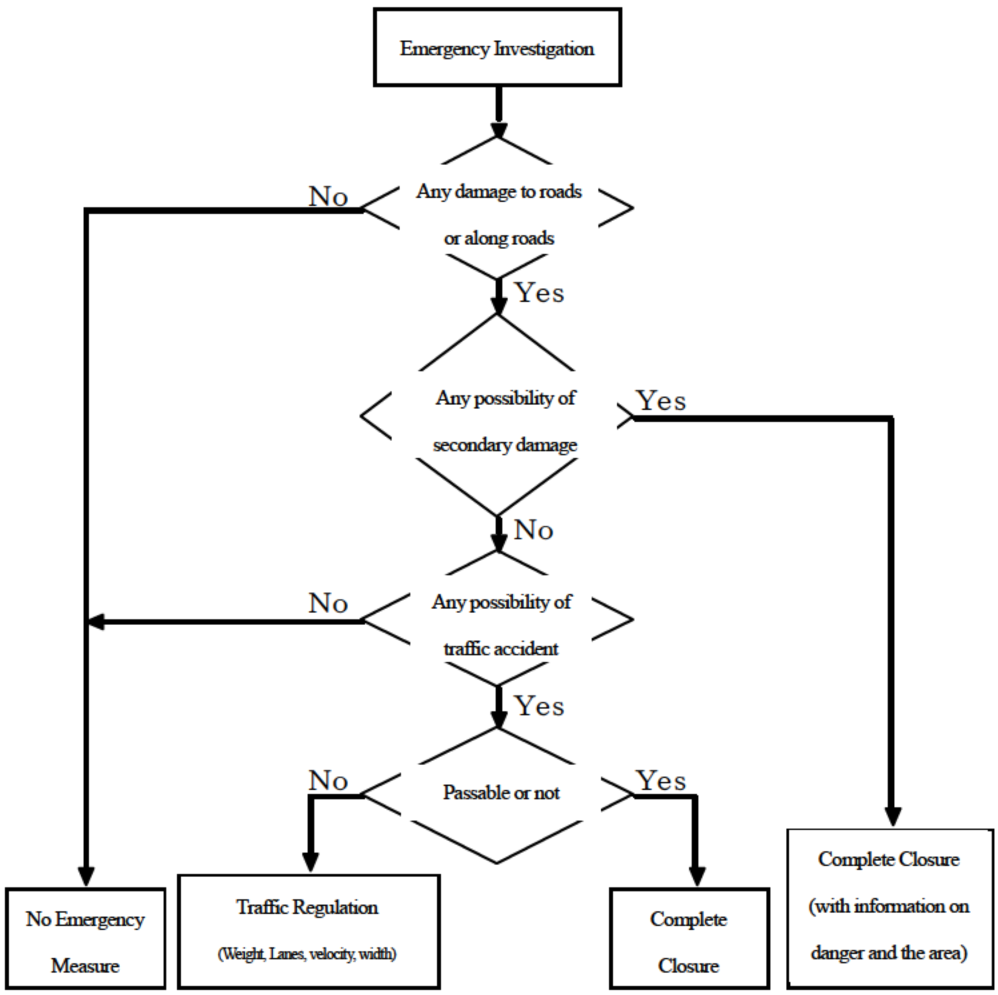


Figure 2.3.1 Flowchart of Emergency Measures for Road Facilities

2) Implementation of Traffic Regulation

About the vulnerable place for traffic grasped by the emergency inspection, traffic regulations including complete closure are made by the judgment of the administrators as shown in the following a). Generally, in this stage, since it is difficult to carry out emergency rehabilitation construction promptly, the attention information to be paid by regulatory signs, signboards, red lights, etc., are provided, the measure of DO NOT ENTER is taken with barricades, ropes, safety corns, etc.

Moreover, it is better to be staffed with workforce at the regulation sections.

a) Responsible Organization of Regulation

i) Road Administrator

Based on Article 46 of the Road Law "prohibition or restriction of passing," a road administrator can determine the prohibition or restriction of passing of roads in order to prevent the danger, when the traffic is vulnerable due to the damage and failure of roads and other reasons, or when there is unavoidable reasons for road construction.

ii) Prefectural Public Safety Commission

Based on Article 76 of the Disaster Measures Basic Law "regulation of the traffic at the time of a disaster," Prefectural Public Safety Commission can specify the section, and can perform traffic regulation for vehicles other than the vehicles which perform emergency transportation, when the urgency is admitted in order to perform disaster emergency measures exactly and smoothly.

Moreover, based on Article 4 of the Road Traffic Law "traffic restriction of the Public Safety Commission," traffic can be regulated when it is admitted that there is necessity in order to prevent the obstacle which causes a possible risk to traffic, to keep the safety and smoothness of traffic.

iii) Policeman

Based on Article 6 of the Road Traffic Law "traffic regulation by policemen," policemen can forbid or restrict the traffic when the urgency is admitted in order to prevent a possible risk to traffic caused by destruction of roads, fires and other situations,

b) Contents of Road Traffic Regulation

According to the damage situation, the type of road traffic regulation is chosen appropriately. It is necessary to take into consideration the change of situations, such as disaster situation, surrounding regional peculiarity, scale of earthquake disaster and range, emergency rehabilitation, and permanent restoration, and to choose about the type of road traffic regulation appropriately.

Moreover, the first priority is given to attain the restoration immediately, and it is better to indicate the restoration schedule time.

c) Others

i) Notification of Emergency Transportation Vehicle

Based on "traffic restriction to vehicles other than the vehicles which perform urgent transportation" which is carried out by the Public Safety Commission at the time of disaster, the certificate of acknowledgement of emergency transportation vehicle is delivered to the vehicles which permit passing (**Figure 2.3.2**).

To contribute to smooth promotion of disaster emergency activities, the prior notification of emergency vehicles can be performed. About what is accepted to correspond to emergency by examination of the Public Safety Commission, the emergency vehicles are provided with prior notification certificate. At the time of a disaster, the check of prior notification vehicles is performed by this proof submitted notice, and a badge and an emergency vehicle certificate of acknowledgement are provided.

In the 2004 Niigata-ken-chuetsu Earthquake, the delivery vans of food supermarket or transportation business were also treated as emergency vehicles by the flexible judgment of the Prefectural Police during the time of closure of the national highway No.17 at Wanazu tunnel. As a result, the relief goods were delivered using Kanetsu Expressway with 2 lane opening of traffic, the transporting condition had been improved significantly, and it contributed to the life of residents in the affected area.

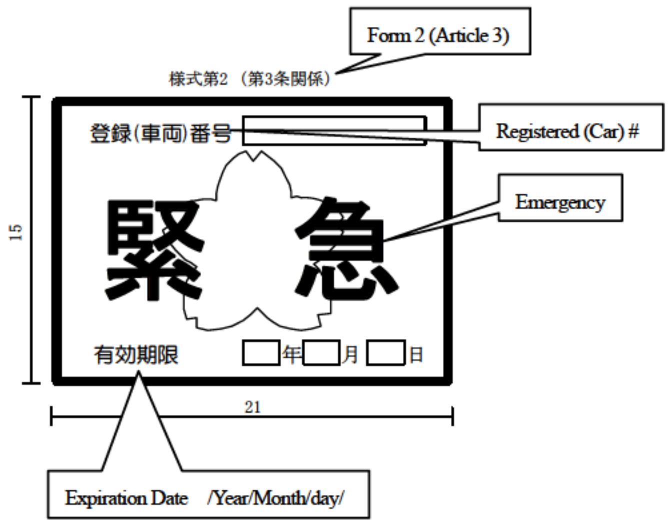


Figure 2.3.2 Badge for Certificate of Acknowledgement of Emergency Transportation Vehicle

ii) Points of Concern at the Time of Release of Traffic Regulation

In the 1995 Hyogo-ken-nanbu Earthquake, there was an example that major traffic jam was generated immediately after the opening of traffic, because it was reported that Chugoku Expressway which had the regulated section in part was "whole-line opening of traffic." Therefore, when announcing the release of the traffic regulation in case of an earthquake disaster, it is necessary to devise a mode of expression so that misunderstanding of the mass media may not be invited.

3. TEMPORARY REPAIR AND RESTORATION FOR BRIDGES

3.1 General

In this section, temporary repair methods for bridge structural members including foundations, piers, abutments, superstructures, bearing supports, unseating prevention devices and expansion joints are presented.

In the phase of emergency investigation, because of the limitation of time, it is generally difficult to make detailed damage inspection, damage evaluation and then the necessary treatment. On the other hand, in the stage of temporary repair, the bridges whose damage were found during the emergency investigation, and the bridges whose damage had the possibility resulting in the destructive damage, the significant progress of damage are investigated. Not only one short time inspection, but several times inspection can be made if necessary, and the investigation by the experts also can be made.

The damage inspection for the temporary repair is made in order to prevent the secondary damage, and to assure the temporary traffic function until the completion of permanent repair work. Therefore, the necessity of the temporary repair is determined based on the load capacity and passage condition to support the temporary traffic function.

However, in particular, when the bridge on the critical roads including emergency traffic roads for the transportation of emergency/rescue goods to the affected sites, there is a case in which it is necessary to recover the traffic function as soon as possible. Therefore, the necessity of the temporary repair works is managed considering the damage situation, importance of the roads, and social characteristics of the affected area. If there is no possibility of the secondary damage and of the effect on emergency activities, there is a case in which the permanent repair works is made with skipping the temporary repair.

In the stage of temporary repair, since the objective of the repair works is to assure the temporary traffic function, the typical temporary repair methods include provision of the temporary supports to the bridge superstructures. When the damage is too heavy and critical, the construction of the temporary bridges is also one of the typical methods.

3.2 Damage Inspection for Temporary Repair

(1) Inspection Items

The inspection has to be made under the condition that it is made at the same time with the emergency treatment to prevent the secondary damage. Therefore, it is necessary to prepare the appropriate plan for the inspection locations, inspection issues, inspection methods and the priority so as not to bother the emergency treatment works.

In the stage of temporary repair, for the bridges in which the damage was found during the emergency inspection, in particular, bridges with the possibility resulting in the destructive damage, and bridges with the significant progress of damage, are inspected. The priority of the inspection points is given to the followings.

1) Damage/Failure of Columns
2) Damage/Failure of Bearings (Bearings and Supporting Concrete)
3) Damage/Failure of Primary Members in Superstructure

(2) Inspection Points and Inspection Method

Figure 3.2.1 shows the typical damage for the bridge structures based on the past earthquake experiences. Therefore, the damage inspection is recommended to be made for these damage points. It should be noted that it is necessary to pay attention to the possibility of the progress of the damage by the traffic and/or aftershocks. If it is difficult to provide the scaffold for the close inspection, it is recommended to provide the inspection vehicle, inspection ship and stepladders depending on the situation of the damaged bridges.

- Foundation
  - Pile Foundation
    - 1 Failure of Pile Top, Residual Displacement
  - Spread and Caisson Foundation
    - 2 Residual Displacement
- Substructure
  - Pier
    - Reinforced Concrete Pier
      - 3 (At Bottom of Pier) Crack and Spalling-off of Concrete, Buckling and Cut of Reinforcing Bar, Tilting of Pier
      - 4 (At Cut-off Point) Crack and Spalling-off of Concrete, Buckling and Cut of Reinforced Bar, Tilting of Pier
      - 5 Shear Crack and Spalling-off of Concrete, Exposure of Reinforcing Bar, Tilting of Pier
      - 6 (At Sudden Change Position of Cross Section and Construction Joint) Crack and Spalling-off of Concrete, Buckling and Cut of Reinforcing Bar, Tilting of Pier
      - 7 (Flame Structure) Crack and Spalling-off of Concrete, Buckling and Cut of Reinforcing Bar, Tilting of Pier
    - Steel Pier
      - 8 Local Buckling, Cracks, Failure of Welded Section, Uneven Outplane Residual Deformation, Tilting of Pier
  - Abutment
    - 9 Crack and Spalling-off of Concrete, Buckling and Cut of Reinforcing Bar, Tilting and Subsidence
- Superstructure
  - Concrete
    - 10 Crack and Failure around Support, Displacement
  - Steel
    - 11 Residual Deformation and Failure of Members around Support, Displacement
- Bearing Support
  - 12 Deformation and Failure of Support and Sole Plate
  - 13 Deformation and Failure of Stopper (Stopper of Upper Support, Side Block of Lower Support)
  - 14 Pulling-out, Bending and Cut of Anchor Bolt
  - 15 Looseness and Cut of Set Bolt (Pin, Roller and Rubber Support)
  - 16 Pulling-out of Pin Cap, Cut of Cap (Pin and Roller Support)
  - 17 Pulling-out of Roller and Rocker (Roller and Rocker Support)
  - 18 Deformation and Failure of Uplift Stopper for Preventing Uplift
  - 19 Crack and Failure of Mortar under Support
  - 20 Crack and Failure of Seat Concrete
- Expansion Joint
  - 21 Falling-off of Joint Filler
  - 22 Failure of Face Plate
  - 23 Cut of Joint Rubber
  - 24 Failure of Anchor Concrete
  - 25 Opening and Contact of Joint
  - 26 Vertical Gap
- Others
  - 27 Failure of Hand-Rail, Damper, Unseating Devices, etc
  - 28 Deformation of Surrounding Soils

Figure 3.2.1 Typical Damage of Bridges (Issues for Detailed Inspection)

The damage inspection for the temporary repair is generally based on the visual inspection. The illustrations and photos are used to report the damage including the damaged section and the extent, damage situation and simple measurement information. The inspection for the foundations and the sections under the ground is generally difficult to be conducted at this stage because of limitation of the equipments and time. To use photos effectively to explain the damage, it is recommended to take them as a full view and close-up views for each important damage so as to understand the damage easily. The full view is to show the outline of damage and close-up views are to show the detailed damage situation. The angle to take photos should be changed, for example, 4 angles for bridge columns. It is also recommended to include the measuring poles in the photos.

The followings show the inspection points for each structural member.

1) Foundation

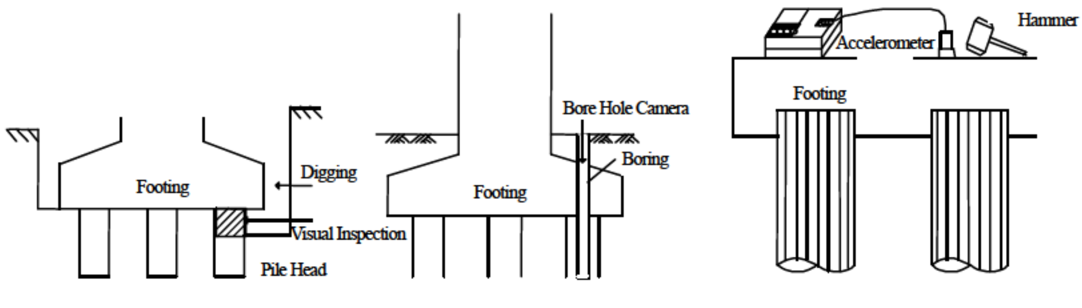
The residual displacement and tilting is inspected based on the visual inspection. It is recommended to inspect the scoring of surrounding soils, crack caused by liquefaction effect, sliding of soft soil and others.

Although it is desirable to inspect the underground sections during the temporary repair stage, the time and cost is necessary more than the simple visual inspection, it is recommended to select the sections in consideration of necessity of the inspection. In general, the detailed inspection is made for the bridges with significant damage over the ground, with significant tilting and subsidence for the piers and abutments, and with the significant deformation of surrounding soils including liquefaction, lateral spreading and settlement.

Outline of the investigation of foundation structures including surrounding soil is shown in **Table 3.2.1**. Moreover, typical investigation methods of foundation structures include the direct viewing by trial digging and the crack investigation using the borehole camera and nondestructive test which were mostly applied for the investigation during the 1995 Hyogo-ken-nanbu earthquake, as shown in **Figure 3.2.2**.

Table 3.2.1 Outline of Investigation Methods of Foundation Structures

Structures	Investigation Items	Investigation Method	Outline
Foundation	Damage Degree	Direct Viewing	Digging the pile head sections, the damage is observed by visual inspection. The possible area to be investigated is limited to pile heads section because of stability of structures and underground water level.
		Indirect Viewing	Core boring is made from the surface of footing into pile and the situation inside the pile is observed by bore hole camera. All pile length can be investigated but it takes time to make boring.
		Non-Destructive	Investigation by elastic wave. Impact wave is generated by hitting the pile head and the disturbance of reflex wave is analyzed and the damage is estimated (Integrity Test).
	Capacity	Loading Test	Residual horizontal capacity and vertical capacity is confirmed by horizontal loading test and vertical loading test using truck.
Surrounding soils	Ground Failure	Direct Viewing	Visual investigation of ground situation around piers and cracks of asphalt road surface.
	Displacement of Piers	Measurement	Horizontal displacement of piers is measured by using GPS and photos, and damage to foundation is estimated by the residual displacement.
	Geology	Boring	Standard penetration test, horizontal loading test in well, in room soil test, PS well logging
		Sampling	Digging the test pit, material of reclamation is confirmed and static and dynamic properties are tested by in-room tests.



(a) Direct Viewing Investigation (b) Indirect Viewing Investigation (c) Non-destructive Investigation (Integrity Test)

Figure 3.2.2 Outline of Typical Investigation Methods for Foundations

2) Reinforced Concrete Pier

It is necessary to evaluate the possibility of re-use of damaged piers with repairing and strengthening, or the necessity of reconstruction works to determine the planning of the permanent repair. Not only by the visual inspection, but it is also recommended to conduct the measurement inspection of the residual displacement and settlement, as well as to check the possibility of the damage progress.

Since the damage section is important as well as the damage degree for the reinforced concrete piers, it is necessary to inspect the damaged locations such as the damage at the bottom of columns, or mid-height section (cut-off section of longitudinal re-bars). The shear span ratio of columns is also important value to know the damage modes. Although the damage mode is variable on the arrangement and volume of lateral re-bars, when the shear span ratio is roughly greater than 3, the damage mode tends to become bending type failure, but when it is less than 3, the damage mode tends to become shear type failure. The inspection should be made for both the longitudinal and transverse directions. The damage of reinforced concrete piers is classified into bending type failure and shear type failure, and the damages progress in the following manners.

a) Bending Type Failure (Photo 3.2.1)

1. Crack of Concrete (Horizontal Crack)
2. Spalling-off of Cover Concrete
3. Buckling of Longitudinal Re-bars
4. Cut of Longitudinal Re-bars and Crash of Core Concrete

b) Shear Type Failure (Photo 3.2.2)

1. Crack of Concrete (Horizontal and Diagonal Crack)
2. Progress of Crack of Concrete
3. Spalling-off of Cover Concrete
4. Exposure of Longitudinal Re-bars
5. Fracture of Lateral Re-bars and Crash of Core Concrete

Therefore, to evaluate the damage degree, it is important to check which level damage in the above is developed at the damaged reinforced concrete columns. It is effective to put the mortal at the damaged section in order to know the possibility of the damage progress caused by the live loads or aftershocks. In this case, the mortar with the length of about 10cm is put at a few important points. When crack or damage is found at the added mortal, the possibility of the progress of the damage is to be considered.

Photo 3.2.1 Bending Type Failure of Reinforced Concrete Columns

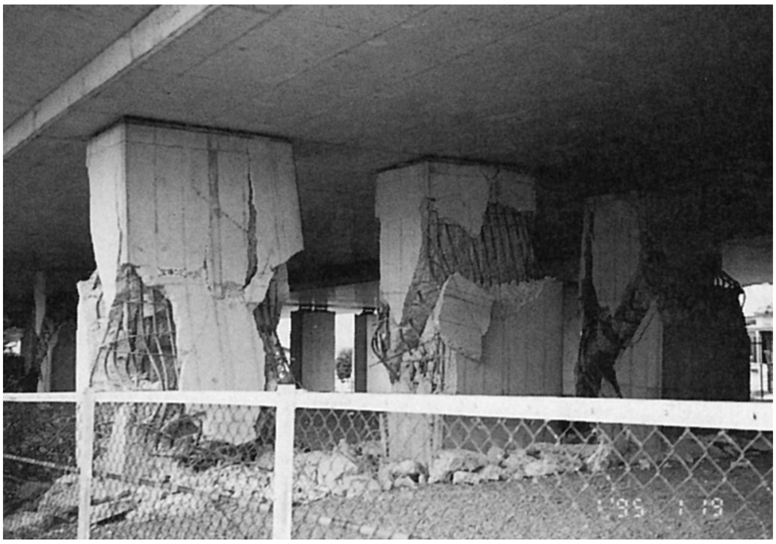


Photo 3.2.2 Shear Type Failure of Reinforced Concrete Columns

The above is for the single column type reinforced concrete piers. The methods can be applied for the flame type piers as well. In the transverse direction of the flame piers, it is recommended to investigate the bending and shear damage at the bottom and top sections of columns and the both ends of lateral beams as shown in **Photo 3.2.3**. When the existing columns were retrofitted by using steel jacketing to enhance the shear and bending strengths, it is recommended to inspect the buckling, crack, or deformation of steel jacket by hammering inspection.

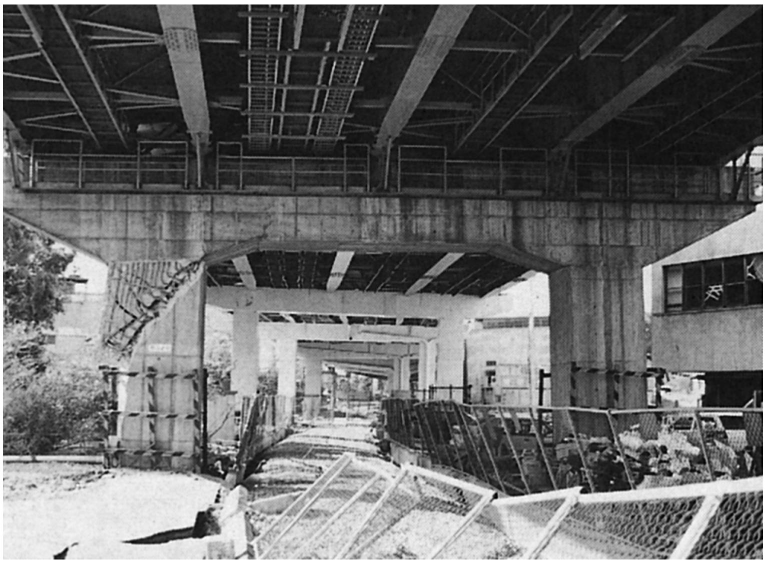


Photo 3.2.3 Bending and Shear Type Damage of Flame Type Piers

3) Abutment

The inspection points for abutments are the same for the reinforced concrete piers as shown in the above. It is important to know where the damage is developed such as abutment wall and foundation, or parapet and wings. In general, the effect of the damage to parapet and wings is not significant for the temporary load capacity and traffic passage condition. However, it should be noted that there is a possibility that the repair of the damaged parapet becomes a larger work in order to reconstruct under the conditions of the closure of roads.

4) Superstructures

a) Concrete Superstructure

Typical damage to concrete superstructures is developed around the bearing supports, in particular, around the fixed bearings. It is recommended to inspect mainly around the bearings. The items to be inspected are crack and spalling-off of concrete, fracture of longitudinal re-bars and fracture of prestressed cables.

b) Steel Superstructure

Typical damage to steel superstructures is developed around the bearing supports, in particular, at the fixed bearings. It is the same as the case for concrete superstructures. The inspection items are the followings.

1. Buckling, deformation and fracture of primary members which directly affect load capacity
2. Buckling, deformation and fracture of secondary members which do not significantly affect load capacity

It should be noted that the primary members include upper and lower flange and web for steel girders, upper, lower and diagonal truss members for truss bridges. The secondary members include those except primary ones such as lateral beams. There is a case that the damage such as buckling and deformation is developed at the mid section of girders not only around the bearing supports for the multi-span continuous girders. **Photo 3.2.4** shows a damage example to the girder end, **Photo 3.2.5** shows buckling of girders at mid section, these damages were found during 1995 Hyogo-ken-nanbu Earthquake.

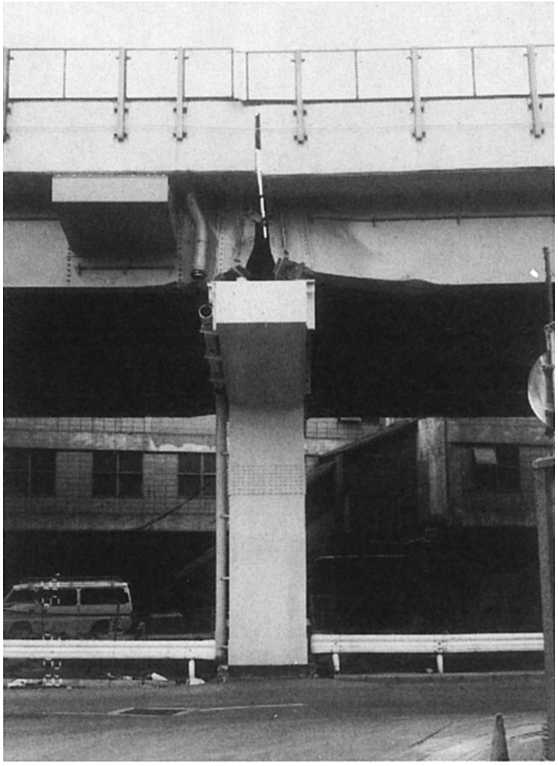


Photo 3.2.4 Damage at Ends of Steel Girders

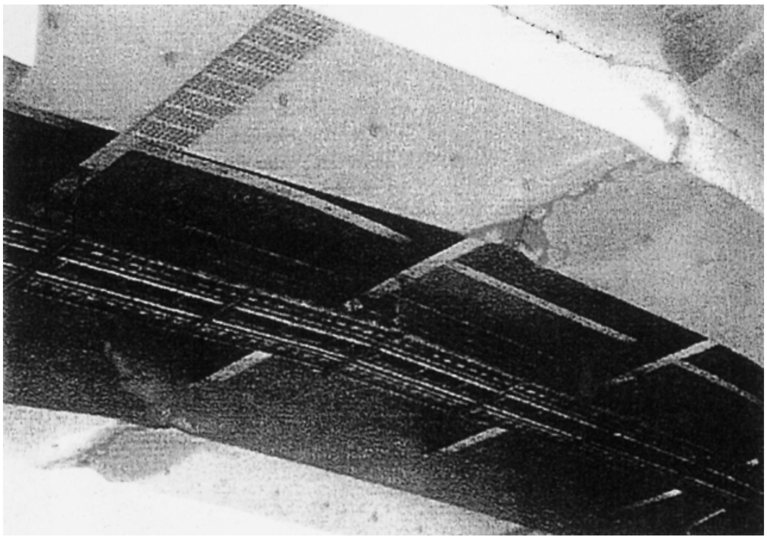


Photo 3.2.5 Buckling of Steel Box Girders at Mid-Section

5) Bearing Support

Since there are several bearing types for practical applications, the damage modes are also different depending on the type of bearings. Since the failures of set bolts (in particular, shear keys are also damaged), side blocks, pins, anchor bolts, and seat concrete lose the lateral load capacity to support the superstructure, there is a possibility that the damage progresses to unseating of the superstructure caused by aftershocks. It is important to inspect such damage and failures. When the significant damage is found at the bearings, attentions should be paid to the movement of the superstructure, tilting and lateral dislodgement of the substructures. The seat width should be checked to prevent unseating of the superstructures caused by the relative displacement between the superstructure and the substructures. **Photo 3.2.6** shows the damage example of pin type bearings which was found during the 1995 Hyogo-ken-nanbu Earthquake.

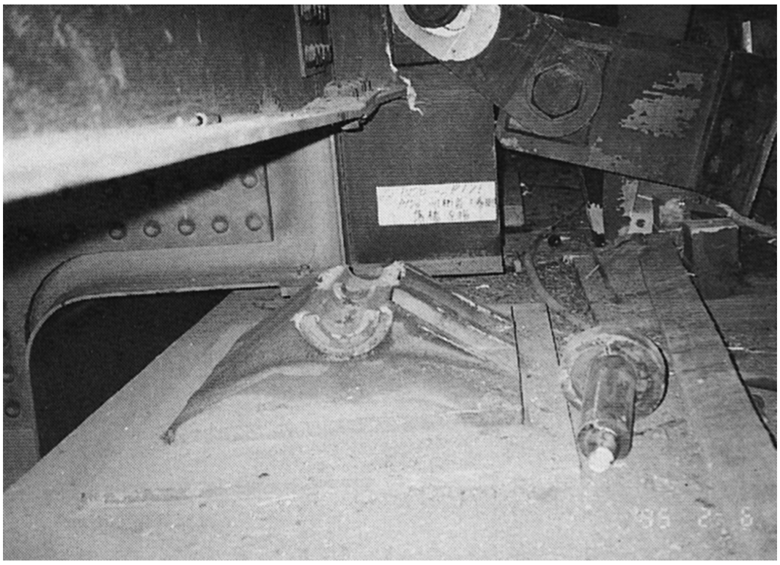


Photo 3.2.6 Damage of Pin Type Steel Bearing

6) Unseating Prevention Device

Unseating prevention devices work to prevent falling-down of superstructures caused by the excessive relative displacement between two adjacent superstructures and between superstructure and substructures. Therefore, it is recommended to investigate the possibility of unseating of the superstructures as well as the damage to bearing supports and girder ends. **Photo 3.2.7** shows the damage example of unseating prevention devices during the 1995 Hyogo-ken-nanbu Earthquake.

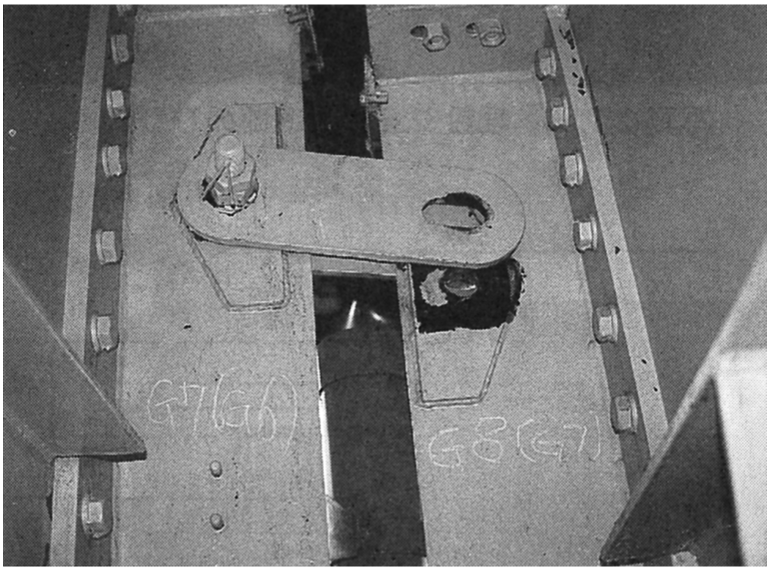


Photo 3.2.7 Damage of Unseating Prevention Devices (Link Type Connection Device)

7) Expansion Joint

It is recommended to inspect the vertical gap and closure and/or opening of expansion joints. **Photo 3.2.8** shows the damage example of expansion joint during the 1995 Hyogo-ken-nanbu Earthquake.

Photo 3.2.8 Damage of Expansion Joint

8) Approach Embankment

The amount of subsidence is to be investigated from the viewpoint of drivability. **Photo 3.2.9**. shows the subsidence situation at the bridge abutment during the 1995 Hyogo-ken-nanbu Earthquake.

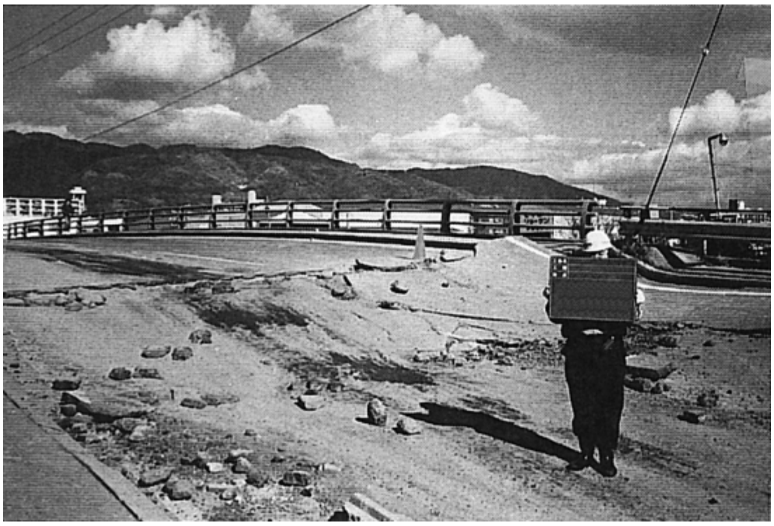


Photo 3.2.9 Settlement of Approach Section (Backfill Soil Section) of Abutment

9) Others

Because of the damage of bearings and collision of adjacent girders, guardrail, safety barrier for vehicles, and noise reduction walls, as well as expansion joints, are damaged often especially at the girder ends. The damage to the safety barrier for vehicles is to be investigated from the viewpoint of the reservation of safe passing space for vehicles and pedestrian's safety. **Photo 3.2.10** and **Photo 3.2.11** show the damage examples of the safety barrier for the vehicles and deformation of noise reduction walls during the 1995 Hyogo-ken-nanbu Earthquake.

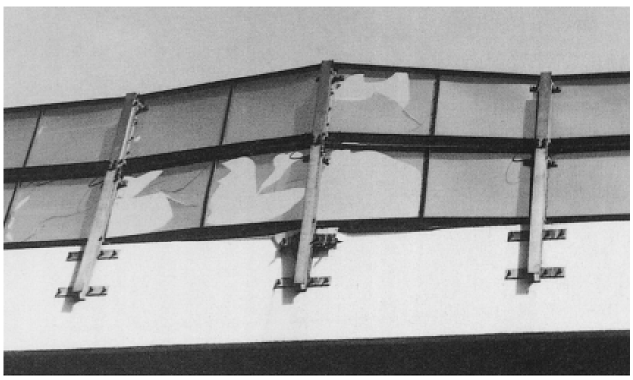


Photo 3.2.10 Damage of Safety Barrier for Vehicles **Photo 3.2.11** Deformation of Noise Reduction Walls

3.3 Evaluation of Damage Degree for Temporary Repair

The objective to evaluate the damage degree of structural members is to judge the temporary repair methods, and to plan the permanent repair works. The standard damage evaluation methods for superstructures, bearing supports, piers and foundations are shown in this section.

(1) Damage Degree

Based on the inspection results for the temporary repair, it is necessary to evaluate the damage degree and then to conduct temporary repair works if necessary. In the stage of temporary repair, it is important to evaluate the damage degree related to the load capacity and passage conditions for short-term until the permanent repair works. In the stage of permanent repair, it is necessary to evaluate the long-term function recovery and the repairability.

The damage degree depending on bearing capacity is classified into 5 ranks, damage degree depending on road surface condition is into 3 ranks, and the repairability is into 2 ranks as shown in the followings.

1) Damage Degree depending on Bearing Capacity

As: Falling-off (Unseating of superstructure, collapsed or half-collapsed.)

A: Critical Damage (Possible critical damage including unseating of superstructure with the damage in which bearing capacity is significantly lost.)

B: Medium Damage (Considerable damage, but may be used for short term service unless progress of damage due to aftershocks and live load is not developed.)

C: Slight Damage (Damaged, but not considerable for short term service.)

D: No Damage (No special damage)

The damage evaluation concept depending on the structural characteristics is shown later.

2) Damage Degree depending on Road Surface Condition

a: Unpassable (Badly damaged, and has to be closed.)

b: Passable with care (Damaged, but can be opened for short term traffic if sufficient care is paid.)

c: No Damage (No special damage)

3) Repairablity

In spite of the damage degree depending on bearing capacity, residual displacement of substructures is developed by the lateral spreading of surrounding soils, movement/tilting/settlement of substructures. The level of displacement is important for the selection of the permanent repair methods. That is strongly related to the design of road alignment, adjustment of height level of bearings and the location of bearings, then the different permanent repair methods is to be selected depending on these residual displacement conditions.

α: Excessive Residual Displacement

(It is recommended to discuss the permanent repair methods including the removal and reconstruction of damaged substructures. The tilted angle to exceed 1/100 (rad) is one of the reference values to reconstruct damaged substructures.)

β: Small Residual Displacement

(The residual displacement is less than the level to conduct the permanent repair by repairing and strengthening of damaged substructures.)

It should be noted that the short term means the time to complete the permanent repair works. The specific period is depending on the whole damage in the area. In the stage of temporary repair in which the detailed inspection cannot be conducted, there is a case in which it is hard to judge the difference between Damage Degree A and B, or B and C. However, the judgment of B and C is related to the possibility to use damaged structures without any temporary repair for short term, and the judgment of A and B is related to the possibility of critical damage including unseating of superstructure without any temporary repair.

Table 3.3.1 shows an inspection sheet to note the inspected results for the temporary repair.

Table 3.3.1 Example of Inspection Sheet for Temporary Repair

<table>
<tr><td colspan="2">Name of Bridge</td><td></td><td>Location</td><td></td><td>Managing Office</td><td></td><td>Inspector</td><td></td><td>Date of Inspection</td><td></td></tr>
<tr><td colspan="3">Inspection Members</td><td colspan="2">Outline of Damage</td><td colspan="3">Damage Degree</td><td colspan="3">Comments</td></tr>
<tr><td rowspan="6">Inspection on Bearing Capacity</td><td colspan="2">1.Foundation</td><td colspan="2"></td><td colspan="3">A, B, C, D</td><td colspan="3"></td></tr>
<tr><td colspan="2">2.Pier</td><td colspan="2"></td><td colspan="3">As, A, B, C, D</td><td colspan="3"></td></tr>
<tr><td colspan="2">3.Abutment</td><td colspan="2"></td><td colspan="3">As, A, B, C, D</td><td colspan="3"></td></tr>
<tr><td colspan="2">4.Superstructure</td><td colspan="2"></td><td colspan="3">As, A, B, C, D</td><td colspan="3"></td></tr>
<tr><td colspan="2">5.Bearing</td><td colspan="2"></td><td colspan="3">A, B, C, D</td><td colspan="3"></td></tr>
<tr><td colspan="4">6. Damage Degree depending on Bearing Capacity
(Select heaviest damage in #1 to #5)</td><td colspan="3">As, A, B, C, D</td><td colspan="3"></td></tr>
<tr><td rowspan="4">Inspection on Road Surface Condition</td><td colspan="2">7.Expansion Joint</td><td colspan="2"></td><td colspan="3">a, b, c</td><td colspan="3"></td></tr>
<tr><td colspan="2">8.Approach Bank
(Settlement)</td><td colspan="2"></td><td colspan="3">a, b, c</td><td colspan="3"></td></tr>
<tr><td colspan="2">9.Guard Rail</td><td colspan="2"></td><td colspan="3">a, b, c</td><td colspan="3"></td></tr>
<tr><td colspan="4">10.Damage Degree depending on Road Surface Condition
(Select heaviest damage in #7 to #9)</td><td colspan="3">a, b, c</td><td colspan="3"></td></tr>
<tr><td colspan="5">Inspection on Repairability</td><td colspan="3">α, β</td><td colspan="3"></td></tr>
<tr><td colspan="5">Criteria of Traffic Control
(#6 and #10)</td><td colspan="3">As, A, B-a, C-a, D-a: Complete Closure
B-b, B-c, C-b, D-b: Traffic Control
C-c, D-c: No need of Temporary Repair</td><td colspan="3"></td></tr>
</table>

(2) Evaluation of Damage Degree for Each Structural Member

Evaluation of damage degree depending bearing capacity is made as follows. These methods are based on the past damage experiences including the 1995 Hyogo-ken-nanbu Earthquake and experimental research results.

1) Foundation

In general, it is hard to find the damage to foundations without excavation. However, when the heavy damage was developed in the foundations in the past earthquakes, piers and superstructures were also damaged by the effect of foundation. Therefore, there is no significant damage at piers and superstructures, the damage degree for the temporary repair may be judged as C (Slight damage) or D (No damage). When the scoring surrounding soils, large cracks caused by the liquefaction, sliding of soft soils are found, the attention should be paid to the residual displacement and/or tilting of foundations. If there is any remarkable deformation, it is recommended to check the damage by the excavation of surrounding soils or using bore-hole camera. When the large residual displacement of superstructures caused by the damage of foundations was found, damage degree can be judged as A (Critical damage). **Table 3.3.2** was used for the damage evaluation of pile foundations during the 1995 Hyogo-ken-nanbu Earthquake.

Table 3.3.2 Damage Degree for Pile Foundation

Damage Degree	Definition
A	Both settlement of foundation and significant residual displacement
B	Significant residual displacement or bending crack at piles
C	Small bending crack at piles
D	No damage or slight crack at piles

Damage degree in **Table 3.3.2** is evaluated using the crack width. **Table 3.3.3** and **Table 3.3.4** are also used to evaluate the damage.

Table 3.3.3 Damage Evaluation using Scoring of Crack Width

Crack Width	Score	Evaluation Criteria
<0.5mm	0	Residual crack before yielding of re-bar
0.5-1.4mm	1	Crack when re-bar strain is in the range of stable yield strength
1.5-2.9mm	2	Crack when re-bar strain is becoming the range of strain hardening
>3.0mm	3	Large crack when re-bar strain is in the range over strain hardening area

Table 3.3.4 Damage Degree Evaluation based on the Scoring of Pile Damage

Score	≥9	5-8	1-4
Damage Degree	B	C	D

2) Reinforced Concrete Pier

Table 3.3.5 shows the concept of damage degree of reinforced concrete piers.

Table 3.3.5 Damage Degree of Reinforced Concrete Piers

Damage Degree	Definition
As	Collapse Significant Damage Deformation
A	Fracture of re-bars or large deformation
B	Fracture of part of re-bars and deformation of re-bars, crack and spalling-off of concrete
C	Crack and local spalling-off of concrete
D	No damage or slight damage with small effect on load capacity

Damage evaluation for reinforced concrete piers may be made using **Table 3.3.6** to **Table 3.3.8** depending on the location of damage. **Table 3.3.6** to **Table 3.3.8** are for bending type failure at bottom of pier, damage at mid-height section (cut-off of longitudinal rebar) and shear type failure, respectively. These are based on the past damage experiences and experimental research. When these tables are used, attentions should be paid to the followings.

a) Damage degree is different depending on the damage location, the locations of crack and spalling-off of concrete should be carefully checked. In general, **Table 3.3.6** is applied for the pier with shear span ratio over 3 and the damage is developed at the bottom pier. **Table 3.3.7** is applied for the pier with shear span ratio over 3 and the damage is developed at mid-height section (cut-off section of longitudinal re-bars). On the other hand, **Table 3.3.8** is applied for the short height pier with shear span ratio less than 3 and the diagonal crack is developed from the top to the bottom of pier.

b) When the volume ratio of longitudinal re-bar is small, the damage looks relatively small. In this case, the row to show the case with small volume ratio of longitudinal re-bars in **Table 3.3.6** may be applied.

c) There are piers, which were constructed in old time, with that the lateral re-bar was arranged inside of longitudinal re-bars. For such piers, damage is more extensive as shown in **Table 3.3.6** to **Table 3.3.8**.

d) Damage evaluation except the above including the damage to sudden change position of cross section, construction joint, and flame members, can be made by using the tables with considering such structural characteristics.

e) There is no example which suffered damage in the past earthquakes for the reinforced concrete bridge columns in which retrofit was carried out by concrete jacketing, steel plate jacketing, and fiber sheet jacketing. Since the improvement in earthquake resistant performance is achieved by retrofit, it is thought that a possibility to suffer serious damage is also low. However, it is difficult to investigate the damage inside the jacketing. The followings are the one method to estimate the damage from the outside view.

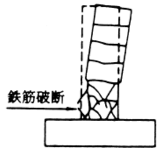
i) For the bridge piers retrofitted by concrete jacketing, **Table 3.3.6** can be applied to the evaluation of damage degree.

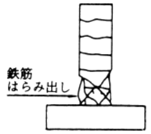
ii) For the bridge piers retrofitted by steel plate jacketing, the concrete surface cannot be viewed. Furthermore, it is usually covered with protection cover concrete at the pier bottom in which the damage is expected for the bending type failure. **Table 3.3.9** shows the proposed method to evaluate the damage degree based on the experimental study. The damage of the crack at the cover concrete and no significant residual displacement can be judged as "C (Slight damage)" or "D (No damage)." When the cover concrete is broken and the compression buckling of the steel plate is found, it is desirable to carry out further detailed investigation of the damaged section.

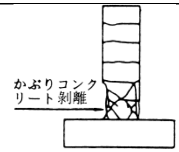
iii) For the bridge piers retrofitted by fiber sheet jacketing, the existence of the fracture of fiber sheet is one of the important points to evaluate the damage degree. When the fracture of fiber sheet and crash of core concrete are found, the damage degree can be "A (Critical damage)." When the fiber sheet is fractured but core concrete are not crashed, it can be "B (Medium damage)." When the slight damage of sheet are found, it can be "C (Slight damage)."

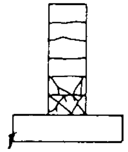
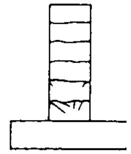
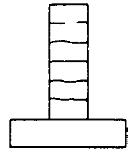
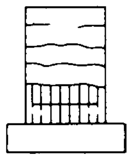
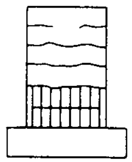
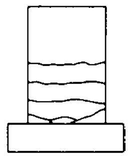
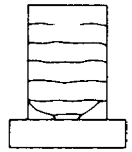
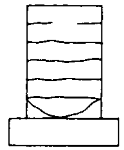
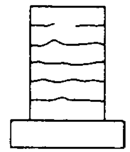
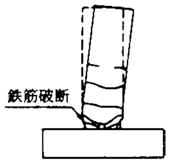
Table 3.3.10 shows the actual damage photos during the 1995 Hyogo-ken-nanbu Earthquake depending on the damage degree shown in **Table 3.3.6** to **Table 3.3.8**.

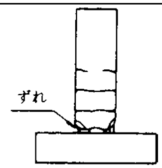
Table 3.3.6 Evaluation of Damage Degree for Reinforced Concrete Pier subjected to Flexural Failure at Base

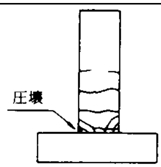
<table>
<tr><td colspan="3">Observed Damage</td><td>1. Failure of Re-bar and Tilting of Pier</td><td>2. Deformation of Rebar</td><td>3. Spalling-off of cover concrete</td><td>4. Diagonal Cracks (Penetrated)</td><td>5. Diagonal Cracks (Not Penetrated)</td><td>6. Only Horizontal Cracks</td></tr>
<tr><td rowspan="4">Damage Situation</td><td rowspan="2">General Case
p≥0.5%</td><td>Side View</td><td>

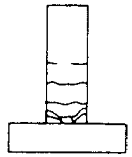
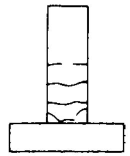
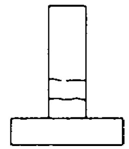
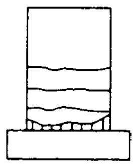
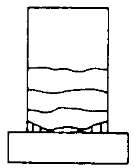
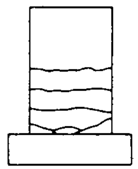
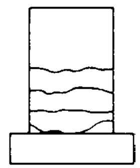
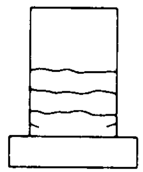
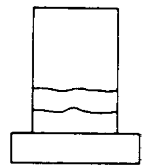
Failure of Re-bar</td><td>

Deformation of Re-bar</td><td>

Spalling-off of Cover Concrete</td><td></td><td></td><td></td></tr>
<tr><td>Front View</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Low Longitudinal Rebar ratio
p<0.5%</td><td>Side View</td><td>

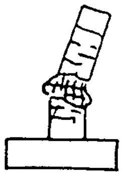
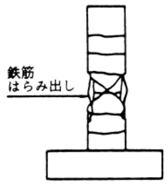
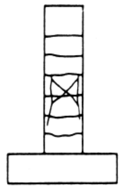
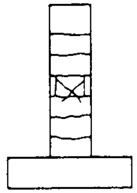
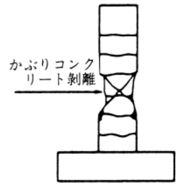
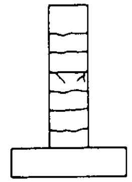
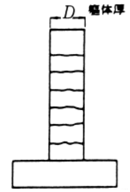
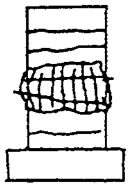
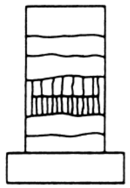
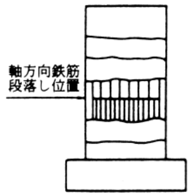
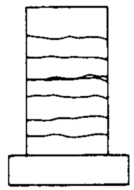
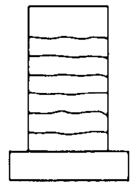
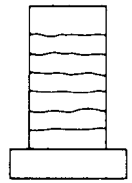
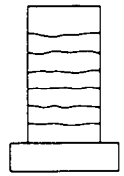
Failure of Re-bar</td><td>

Displacement</td><td>

Crash of Concrete</td><td></td><td></td><td></td></tr>
<tr><td>Front View</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Damage Degree</td><td>A: Critical Damage</td><td>B: Medium Damage</td><td>B: Medium Damage</td><td>C: Slight Damage</td><td>C: Slight Damage</td><td>C: Slight Damage</td></tr>
<tr><td colspan="3">Residual Strength</td><td>Less than P_y</td><td>Less than P_y</td><td>$1.0P_y$</td><td>$1.1P_y$</td><td>P_u
($1.1P_y$-$1.3P_y$)</td><td>P_u
($1.1P_y$-$1.3P_y$)</td></tr>
<tr><td colspan="3">Residual Ductility
$\frac{\delta_u - \delta}{\delta_u - \delta_y} \times 100(\%)$</td><td>0%</td><td>0%</td><td>10%</td><td>30%</td><td>50%</td><td>70%</td></tr>
</table>

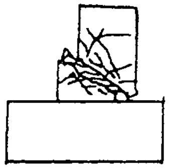
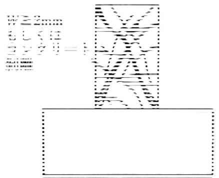
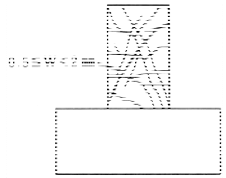
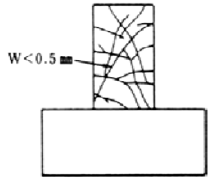
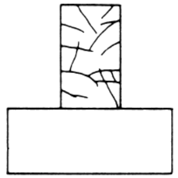
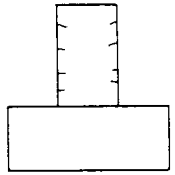
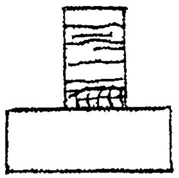
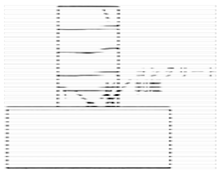
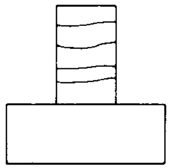
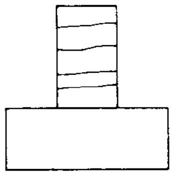
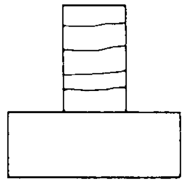
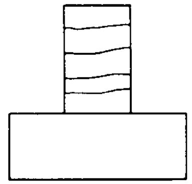
Note) p: Ratio of Longitudinal Re-bar, P_y: Yield Strength, P_u: Ultimate Strength, δ_y: Yield Displacement, δ_u: Ultimate Displacement, δ: Maximum Response Displacement

Table 3.3.7 Evaluation of Damage Degree for Reinforced Concrete Pier subjected to Damage at Mid-Height Cut-off Section of Longitudinal Re-bars

Observed Damage		1. Failure of Re-bars Crack of Core Concrete	2. Deformation of Re-bar	3. Spalling-off of Cover Concrete	4. Diagonal Cracks Penetrated (Progress of Vertical Cracks)	5. Diagonal Cracks (Greater than D/2)	6. Diagonal Cracks (Less than D/2)	7. Horizontal Cracks
Damage Situation	Side View		 Deformation of Re-bar			 Spalling-off of Cover Concrete		 D: Thickness of Column
	Front View			 Cut-off Section of Longitudinal Re-bar				
Damage Degree		As: Near Collapse	A: Critical Damage	B: Medium Damage	B: Medium Damage	C: Slight Damage	C: Slight Damage	C: Slight Damage
Residual Strength			Less than P_y	Less than P_y	$1.0P_y$	$1.0P_y$	P_u ($1.05P_y$-$1.1P_y$)	P_u ($1.05P_y$-$1.1P_y$)
Residual Ductility $\frac{\delta_u - \delta}{\delta_u - \delta_y} \times 100(\%)$			0%	0%	10%	40%	70%	100%

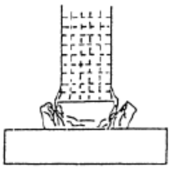
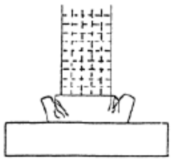
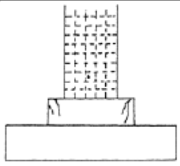
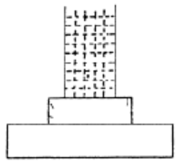
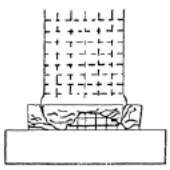
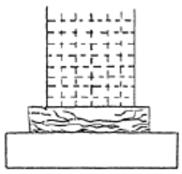
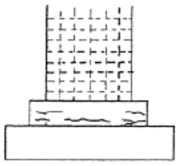
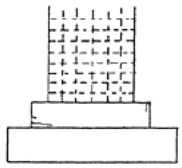
Note) P_y: Yield Strength, P_u: Ultimate Strength, δ_y: Yield Displacement, δ_u: Ultimate Displacement, δ: Maximum Response Displacement, D: Thickness of Column

Table 3.3.8 Evaluation of Damage Degree for Reinforced Concrete Pier subjected to Shear Failure

Observed Damage		1. Dislodgement and Settlement at Shear Failure	2. Diagonal Crack Width W≥2mm	3. Diagonal Crack Width 0.5mm≤W<2mm	4. Diagonal Crack (Penetrated) (Crack Width W≤0.5mm)	5. Diagonal Cracks (Not Penetrated)	6. Only Horizontal Cracks
Damage Situation	Side View		 W≥2 mm or Spalling-off of Cover Concrete	 0.5≤W<2mm	 W<0.5mm		
	Front View		 Spalling-off of Cover Concrete				
Damage Degree		As: Near Collapse	A: Critical Damage	B: Medium Damage	B: Medium Damage	B: Medium Damage	C: Slight Damage
Residual Strength			Less than P_y	around P_y	P_u	P_u	P_u
Residual Ductility $\frac{\delta_u - \delta}{\delta_u - \delta_y} \times 100(\%)$			0%	0-50%	50-100%	100%	100%

Note) P_y: Yield Strength, P_u: Ultimate Strength, δ_y: Yield Displacement, δ_u: Ultimate Displacement, δ: Maximum Response Displacement

Table 3.3.9 Proposed Method to evaluate Damage Degree for Reinforced Concrete Pier retrofitted by Steel Plate Jacketing

Observed Damage		Buckling of Steel Plate	Failure of Bottom Cover Concrete	Crack of Bottom Cover Concrete	Slight Crack of Bottom Cover Concrete
Steel Plate Jacketing	Side View				
	Front View				
Damage Degree		A: Critical Damage	B: Medium Damage	C: Slight Damage	D: Small or No Damage

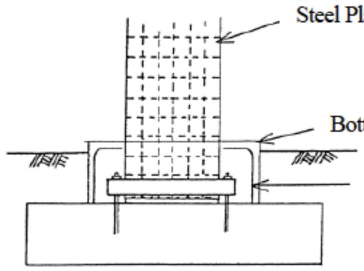


Table3.3.10(1) Evaluation of Damage Degree of Reinforced Concrete Piers
(Damage caused by 1995 Hyogo-ken-nanbu Earthquake)

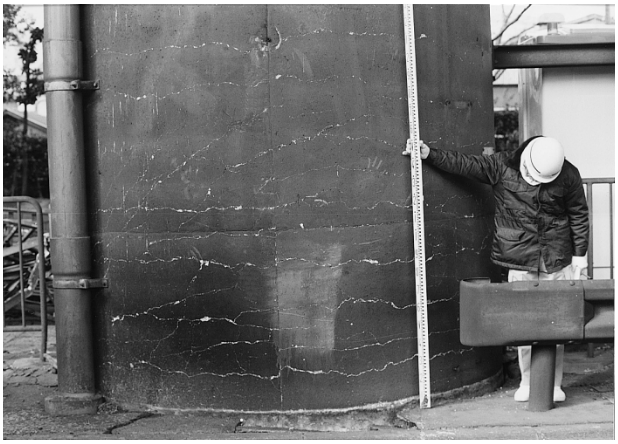
Damage Evaluation of Reinforced Concrete Piers (Single Columns) (Bending Failure)	Damage Degree: Rank A	 
	Damage Degree: Rank B	
	Damage Degree: Rank C	

Table 3.3.10(2) Evaluation of Damage Degree of Reinforced Concrete Piers
(Damage caused by 1995 Hyogo-ken-nanbu Earthquake)

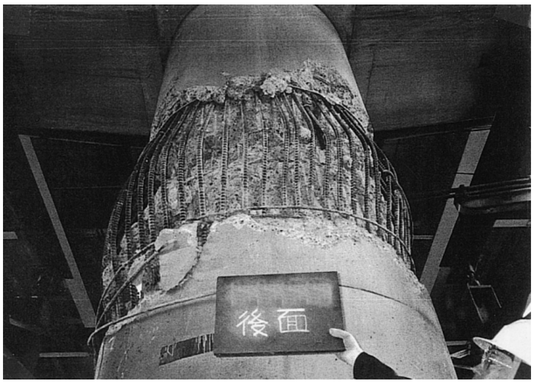
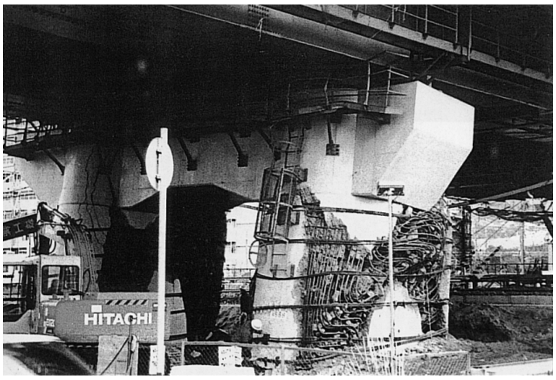
Damage Evaluation of Reinforced Concrete Piers (Single Columns) (Damage at Mid-Height Section, Cut-off Section)	Damage Degree: Rank A	 
	Damage Degree: Rank B	 
	Damage Degree: Rank C	

Table 3.3.10(3) Evaluation of Damage Degree of Reinforced Concrete Piers
(Damage caused by 1995 Hyogo-ken-nanbu Earthquake)

Damage Evaluation of Reinforced Concrete Piers (Single Columns) (Shear Type Failure)	Damage Degree: Rank As	
	Damage Degree: Rank A	
	Damage Degree: Rank B	
	Damage Degree: Rank C	 

Table 3.3.10(4) Evaluation of Damage Degree of Reinforced Concrete Piers
(Damage caused by 1995 Hyogo-ken-nanbu Earthquake)

Damage Evaluation of Reinforced Concrete Piers (Flame Columns)	Damage Degree: Rank As		
	Damage Degree: Rank A		
	Damage Degree: Rank B		

3) Abutment

Damage evaluation for abutments can be made according to the same criteria for the piers shown in the above. Damage to parapet and wing such as cracks may be judged as C(Slight damage).

4) Superstructure

Damage evaluation for superstructure can be made according to **Table 3.3.11**.

Table 3.3.11 Damage Degree for Superstructure

Damage Degree	Definition
As	Unseating of superstructure
A	Steel Girder: deformation of lower flange or significant local buckling of web Concrete Girder: significant spalling-off of concrete Truss: fracture of primary members
B	Steel Girder: deformation of lower flange or local buckling of web Concrete Girder: large cracks and spalling-off of concrete Truss: buckling or deformation of primary members
C	Steel Girder: local or small deformation or buckling Concrete Girder: cracks Steel Girder and Truss: deformation or buckling of secondary members
D	No damage or slight damage without effect on bearing capacity

a) Concrete Girder

Typical earthquake damage to concrete girders including reinforced concrete girder and prestressed concrete girder is developed around bearings supports. The earthquake force is concentrated at the bearing supports and then the damage is developed to the weak section of superstructure and bearings. In general, the strength of bearings is stronger than those of other connecting members, the damage may be developed at girders. The damage can be judges as C (Slight damage) when the crack width is less than 2mm. When crack is greater than 1cm or spalling-off of concrete is developed, since the resistance against lateral forces is not expected, the damage can be judges as B (Medium damage). When several longitudinal re-bars or prestressing cables are fractured as well as failure of bearings, the damage can be judged as A (Critical damage).

Table 3.3.12 shows the damage evaluation of concrete girders.

b) Steel Girder

When the fracture of primary members of truss girder such as upper, lower and diagonal truss members is developed, the damage degree is judged as A (Critical damage). In this damage situation, the clear overall deformation generally can be recognized. When the buckling or deformation is developed at primary members but without any damage progress, the damage degree may be judges as B (Medium damage). The fracture or deformation of secondary members such as lateral members, which do not affect significantly the bearing capacity, may be judged as C (Slight damage). However, even the damage is developed secondary members, the number of damage members is large, the damage should be judges as B (Medium damage) or A (Critical damage) depending on the damage situation.

Table 3.3.13 shows damage evaluation for steel girders. **Table 3.3.14** shows the example of damage evaluation during the 1995 Hyogo-ken-nanbu Earthquake.

Table 3.3.12 Evaluation of Damage Degree of Concrete Girder

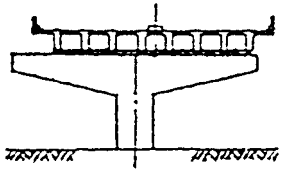
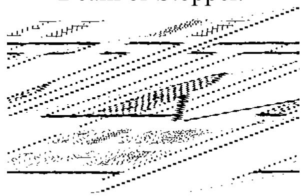
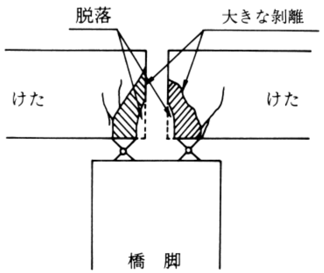
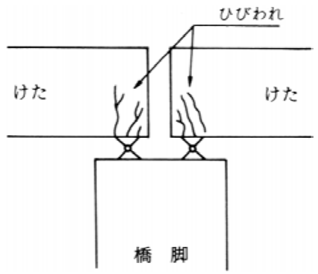
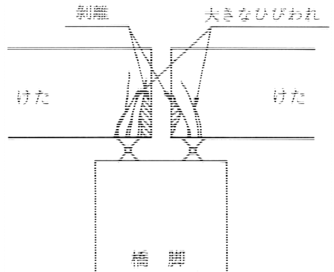
	A: Critical Damage	B: Medium Damage	C: Slight Damage	D: No Damage
Damage of Primary Member		Excessive Displacement over Original Position 	Damage to Superstructure but No Effect for Short Term	Slight Damage
Damage of Secondary Member			Significant Damage and Replacement/Repair/Strengthening is necessary. Damage to Lateral Beam or Stopper.  Spalling-off, Cracks of Cover Concrete	Medium Level Damage
Bearing Support	 Girder, Spalling-off and Falling-down of Concrete, Pier	 Girder, Crack, Pier	 Girder, Large Crack, Spalling-off Concrete	

Table 3.3.13(1) Evaluation of Damage Degree of Steel Girder

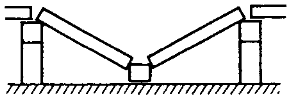
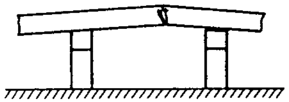
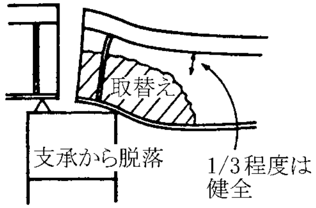
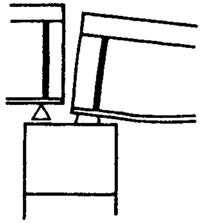
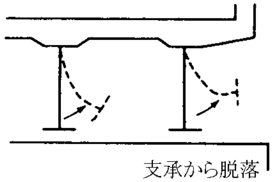
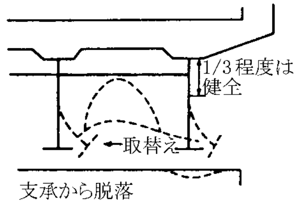
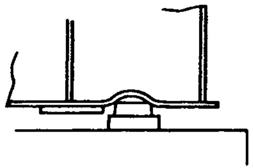
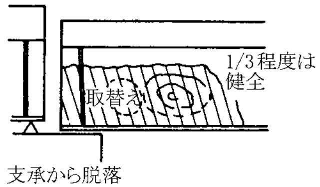
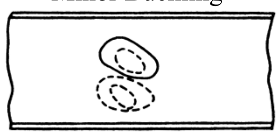
	As: Falling-down of Superstructures	A: Critical Damage	B: Medium Damage	C: Slight Damage	D: No damage
Deformation of Girder	Unseating 	Bending of Girder 	Significant Deformation  Dislocation from Bearing Replacement No Damage about 1/3 Region	Bending of girder or minor deformation 	Deformation with spall-off of paint Slight Buckling Local Fracture Damage to Connecting Bolts
Around Bearing support		Deformation of Concrete Slab  Dislocation from Bearing	Significant Deformation  Dislocation from Bearing Replacement No Damage about 1/3 Region	Local deformation 	
Buckling of Web			Significant Buckling and cracks  Dislocation from Bearing Replacement No Damage about 1/3 Region	Minor Buckling 	

Table 3.3.13(2) Evaluation of Damage Degree of Steel Girder

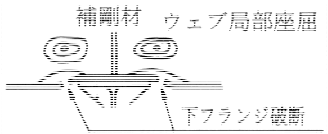
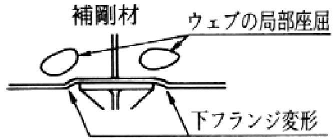
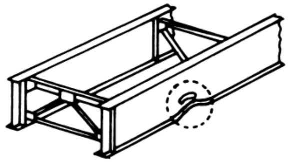
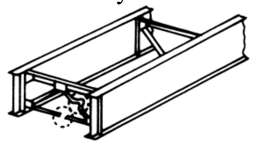
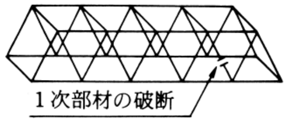
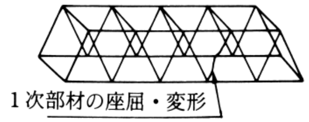
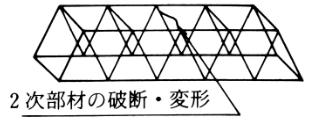
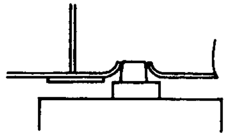
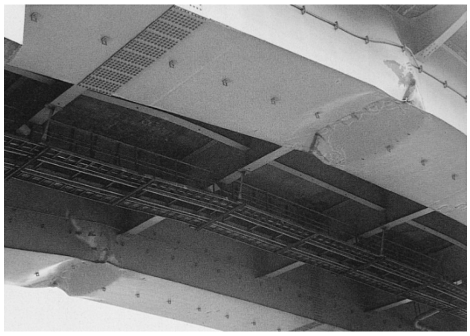
	As: Falling-down of Superstructure	A: Critical Damage	B：Medium Damage	C: Slight damage	D: No damage
Around Bearing Support		 Vertical Stiffener Local Buckling of Web Fracture of Lower Flange	 Vertical Stiffener Local Buckling of Web Deformation of Lower Flange		
Steel Girder			Deformation or Buckling of Primary Members 	Fracture or Deformation of Secondary Members 	
Truss		 Fracture of Primary Member	 Buckling and Deformation of Primary Member	 Fracture or Deformation of Secondary Member	
Others		Instability caused by the Structural Change including Damage of Adjacent Girders	Damage of Superstructure by Intrusion of Bearings 	Slight Deformation with Peeling of Paint Slight Buckling Localized Crack Damage of Bolts	

Table 3.3.14 Evaluation of Damage Degree of Superstructure
(Damage caused by 1995 Hyogo-ken-nanbu Earthquake)

Damage Degree: Rank As (Falling-down)	 
Damage Degree: Rank A (Bending deformation and Buckling of Girder)	 
Damage Degree: Rank B-C (Damage and buckling of Girder end)	 

5) Bearing Support

The damage evaluation can be made according to the concept shown in **Table 3.3.15** and **Table 3.3.16**. Fracture of set bolts, damage to sole plate and shear keys, fracture of anchor bolts and significant failure of seat concrete may be judge as A (Critical damage) since the resistance is lost against aftershocks.

When the girder moves excessively and there is not enough seat length and then possibility to result in the unseating of superstructure, the damage should be judged as A (Critical damage). However, the displacement is less than the space of movable bearing, the damage may be judged as C (Slight damage).

Table 3.3.15 Damage Degree of Bearing Support

Damage Degree	Definition
A	Fracture of set bolts and anchor bolts, damage of sole plate and shear keys Damage of seat concrete
B	Fracture of pin, stopper of upper shoe Pull-out of roller, anchor bolt Fracture of stopper
C	Deformation of upper and lower shoes Looseness of set bolts Deformation or crack of stopper Crack of seat concrete and mortal
D	No damage or slight damage which does not affect bearing capacity

Table 3.3.16(1) Evaluation of Damage Degree of Bearing Supports

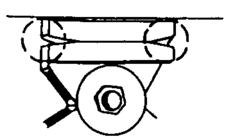
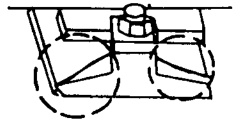
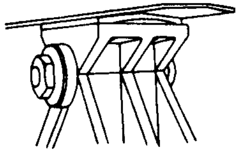
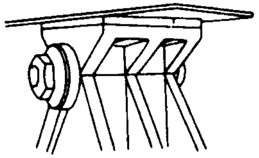
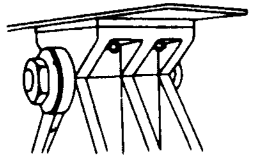
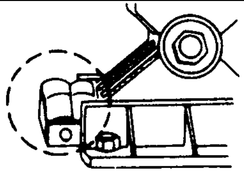
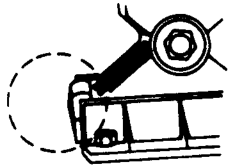
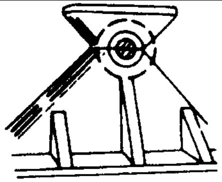
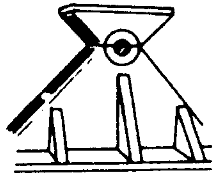
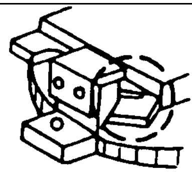
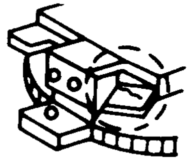
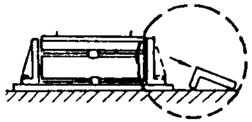
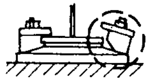
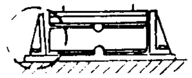
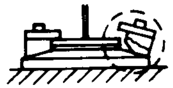
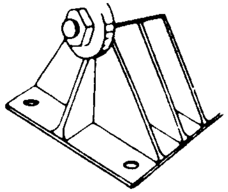
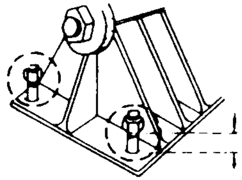
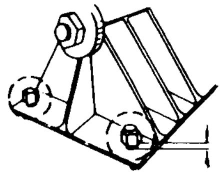
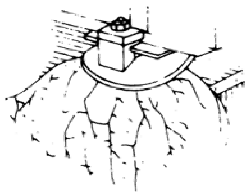
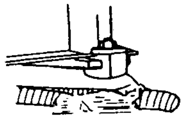
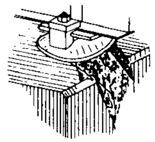
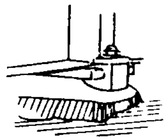
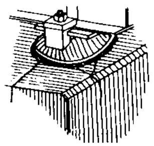
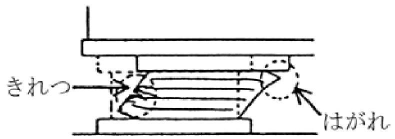
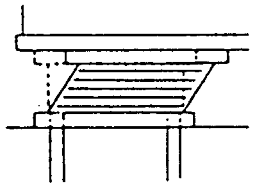
	A: Critical Damage	B: Medium Damage	C: Slight Damage
Upper and Lower Shoe Members		Cracks of Upper Shoe	 Deformation of Upper Shoe  Deformation or Fracture of Lower Shoe
Set Bolts	 Failure of Set Bolts, Damage of Sole Plate and Shear Keys	 Failure of Set Bolts	 Looseness of set bolts
Roller		 Significant Pull-out of Roller	 Pull-out of Roller
Pin and Pin cap		 Failure of Pin	 Pull-out of Pin Cap
Stopper of Upper Shoe		 Failure of Stopper of Upper Shoe	 Crack of Stopper of Upper Shoe

Table 3.3.16(2) Evaluation of Damage Degree of Bearing Support

	A: Critical Damage	B: Medium Damage	C: Slight Damage
Side Block		 Failure of Fixed Bolts  Failure of Uplift Stopper	 Deformation of Side Block  Crack of Uplift Stopper
Anchor Bolt	 Failure of Anchor Bolt	 Pull-out of Anchor Bolt (Over 1cm)	 Pull-out of Anchor Bolt (Less than 1cm)
Seat Concrete and Mortar	 Significant Failure of Seat Concrete	 Failure of Seat Mortar  Failure of Seat Concrete	 Crack of Seat Mortar  Cracks of Seat Concrete
Rubber Bearing	Failure of Rubber Layer	 Crack of Rubber Crack Peeling-off	 Residual Displacement of Rubber Bearing

(3) Evaluation of Damage Degree depending on Road Surface Condition

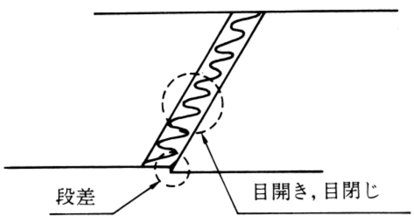
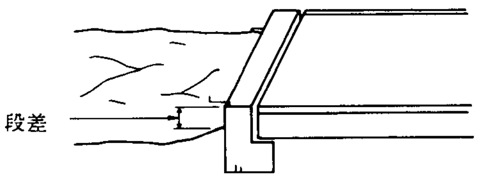
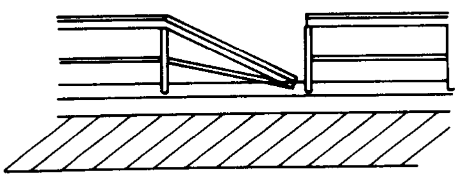
Damage degree on passage condition can be made as follows.

When the bearing is damaged but unseating prevention devices are still effective, the damage degree on passage condition may be judged based on the gap of road surface. When the gap can not be easily recovered, damage degree should be judges as a (Closure), when it is possible to recovered, the damage degree may be judges as b (Passable with care).

When expansion joint is damaged or vertical and horizontal gap is developed, damage degree on passage condition is evaluated according to **Table 3.3.17**. When the passable condition is affected, the damage degree is judged as a (Closure) and b (Passable with care) depending on the damage.

The specific value of vertical gap which affects the passage condition can not be one value because it is changeable depending on damage situation and the importance of the roads. In general, 50-100mm gap does not significantly affect the passage of emergency vehicles.

Table 3.3.17 Evaluation of Damage Degree on Passage Condition

	Damage	Damage Degree
Expansion	 Gap Opening or Closing of Joint	Considering vertical and horizontal gap and the passability, a: Closure, or b: Passable with care
Connecting Bank	 Gap	Considering settlement of bank soils and the passability, a: Closure, or b: Passable with care
Guard Rail		Considering the safety of passengers, a: Closure, or b: Passable with care

(4) Evaluation Criteria of Temporary Repair

It is required to improve the traffic regulation carried out as the emergency measure from the viewpoints of early traffic functional recovery or prevention of secondary damage based on the result of investigation for the temporary repair.

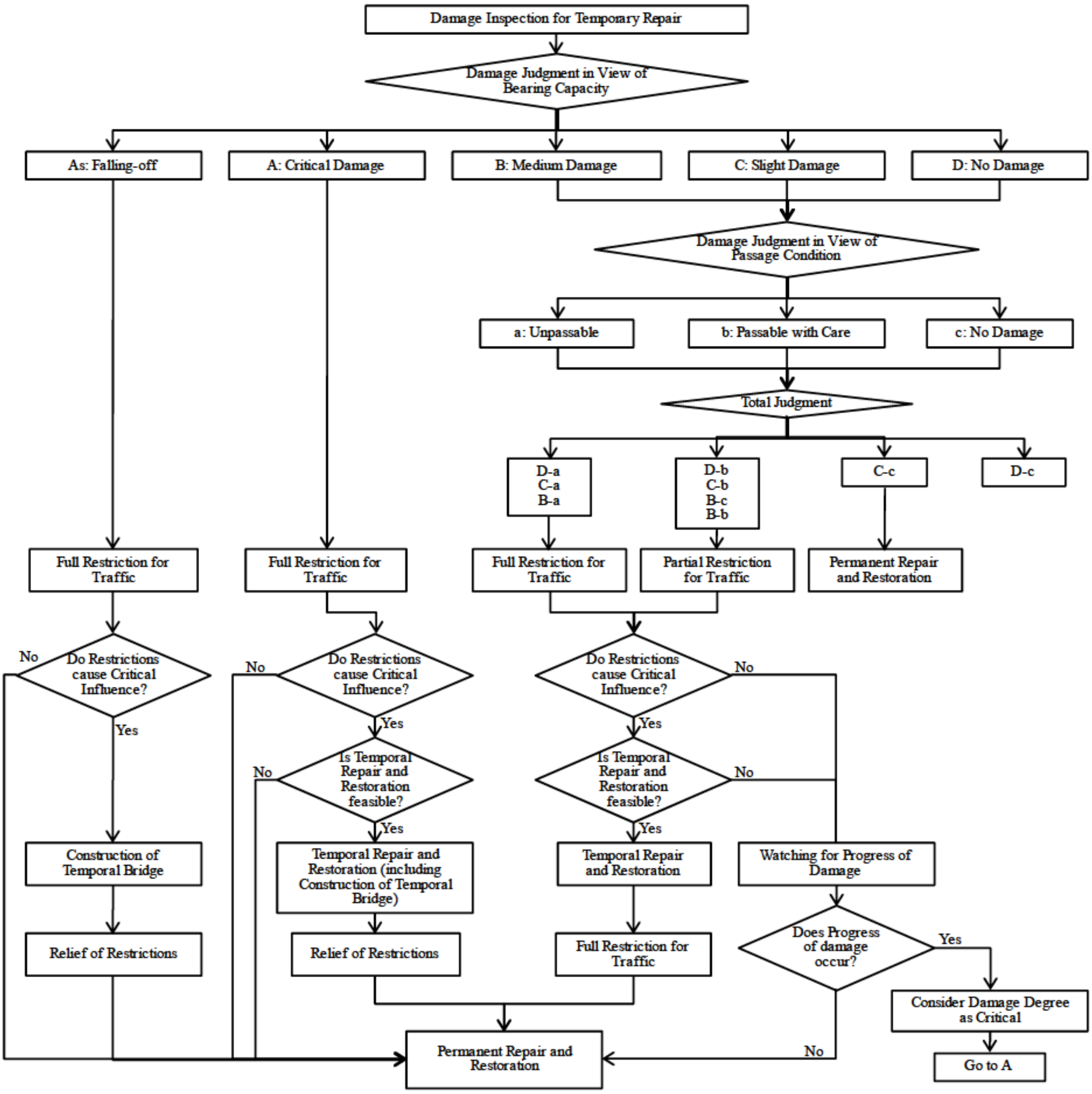
Regarding the traffic regulation at the stage of the investigation for temporary repair, a comprehensive judgment can be made according to **Figure 3.3.1**, by writing down the investigation results in the record vote shown in **Table 3.3.1**, by selecting the largest damage degrees from the investigation results on five items on bearing capacity including 1) foundation, 2) pier, 3) abutment, 4) superstructure and 5) bearing, and from the investigation results on three items on drivability including 7) expansion joint, 8) approach bank, and 9) safety barriers for vehicles. However, it should be noted that **Figure 3.3.1** is just one standard method to judge the traffic regulation, and it is important to judge appropriately according to the specific damage situation.

(5) Safety for Temporary Repair

The temporary repair works are made in order to assure the temporary traffic function and to prevent the secondary damage. The temporary repair methods should be determined based on the appropriate evaluation of residual strength of damaged bridge as well as considering the traffic until the completion of permanent repair and restoration, and earthquake effect by aftershocks.

However, scales, occurrence time term, and the number of times of aftershocks vary greatly with earthquakes and it is difficult to presume the earthquake intensity of aftershocks correctly at the present. Therefore, the treatment is judged individually based on the damage situation and the importance of roads, and surrounding regional peculiarity. There are the following emergency rehabilitation examples in the past earthquakes.

1) In the emergency rehabilitation of Hanshin Expressway during the 1995 Hyogo-ken-nanbu Earthquake, the temporary vents which was designed using the design horizontal seismic coefficient of 0.1 were provided. And when the piers were damaged seriously at the bottom, steel forms were provided around the piers and the concrete were placed in to prevent the secondary damage. Moreover, in the sections which had possibility of unseating by aftershocks, there was an example in which the tiltmeter was provided to monitor the progress of damage.
2) In the 2004 Niigata-ken-chuetsu Earthquake, there was a example in which the bending-shear damage at the cut-off section of reinforced concrete columns was repaired by filling mortar into the damaged section and then by rolling up the carbon fiber sheets to secure the shear strength for the recovery of traffic function temporarily.



		Damage Judgment in View of Bearing Capacity		
		B	C	D
Damage Judgment in View of Passage Condition	a	Full Restriction	Full Restriction	Full Restriction
	b	Partial Restriction	Partial Restriction	Partial Restriction
	c	Partial Restriction	Not Needed	Not Needed

Figure 3.3.1 Procedure of Judgment for Temporary Repair

3.4 Temporary Repair Methods

Table 3.4.1 shows the temporary repair methods for the bridges with damage which affects bearing capacity, and **Table 3.4.2** shows those for the bridges with damage which affects passage conditions.

Table 3.4.1 Temporary Repair Methods to Prevent Damage Progress

Damage Degree	Emergency Measure	Temporary Repair Methods
As	Full Restriction	Construction of Temporary Bridge if necessary
A	Full Restriction	Provision of Unseating Measures if necessary
B	Partial Restriction	Conduct if necessary
C	Caution Mark	Not needed
D	Not needed	Not needed

Table 3.4.2 Temporary Repair Methods to Assure Passable Condition

Damage Degree	Emergency Measure	Temporary Repair Methods
a	Full Restriction	Conduct if necessary
b	Partial Restriction	Conduct if necessary
c	Not needed	Not needed

(1) Recovery of Traffic Function by Temporary Bridge

When the unseating of superstructures occurred, in consideration of the influence of complete closure of traffic, the emergency rehabilitation by installation of an emergency assembly bridge is performed if needed. **Figure 3.4.1** shows an example to construct the temporary bridge consisted of steel pipes for the substructure and steel plate on the H-shaped beam for superstructure during the 1978 Miyagi-ken-oki Earthquake.

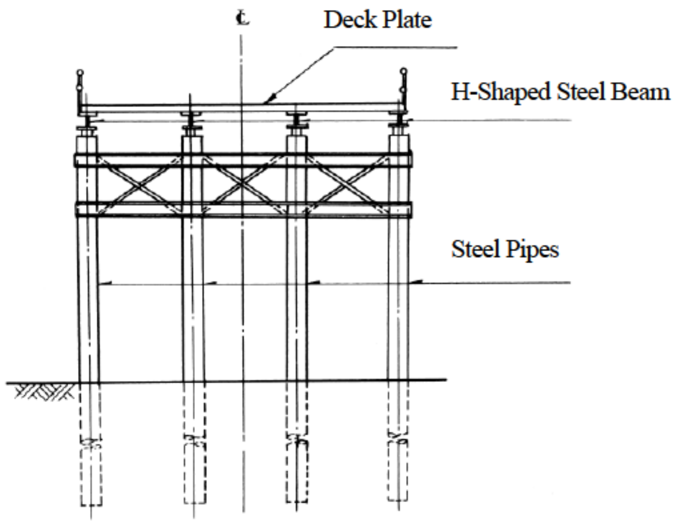


Figure 3.4.1 Temporary Bridge used during the 1978 Miyagi-ken-oki Earthquake

(2) Temporary Repair Methods to Prevent Damage Progress

When the damage depending on the bearing capacity is judged as A (Critical) or B (Medium), it is recommended to conduct the temporary repair selecting from the following methods to prevent the damage progress. These methods can be applied to prevent the secondary damages.

1) Injection of Resin

Resin injection into cracks of concrete members is made for preventing the damage progress as well as corrosion of re-bars.

2) Fiber Sheet Jacketing

When the reinforced concrete columns is damaged as spalling-off of concrete, deformation of longitudinal and lateral re-bars, fiber sheet jacketing methods can be applied to recover shear strength and ductility temporarily. **Photo 3.4.1** shows the example of the application. The damaged section is covered by the mortal and jacketed by carbon fiber sheet.

(a) Damage Situation (b) Repair of Cover Concrete (c) Fiber Sheet Jacketing

Photo 3.4.1 Repair and Strengthening using Fiber Sheet Jacketing

3) Correction of Deformation, Installation of Stiffening Member and/or Alternative Member

When there found the damage or deformation of steel members, the progress of damage is prevented and strength of members is recovered by correction of deformation, installation of stiffening members and/or alternative members (**Figure 3.4.2 - Figure 3.4.4**).

Since the welding situation is greatly influenced by the working environment, it is necessary to consider welding joint shape, welding position, welding rod, welding conditions, and the work environment beforehand. Especially SS material used for rivet structure has high carbon (C) content, or since the high inclusion of Sulfur (S) and the maldistribution of Lynn (P) is also remarkable, it requires cautions for welding. Moreover, since the restraint of joints and the cooling rate of heat influence component may become large, and hardening and embrittlement, or crack may be caused when plate thickness becomes large even if it is SM material, measures such as using the welding rod of low-hydrogen type, or carrying out remaining heat are required in consideration of weldability.

Furthermore, especially for the site welding, attention must be paid for the following points.

a) Since the traffic vibration causes bad influence to welding, it is essential to make welding after closing the traffic.

b) The scaffold is to be secured so that the welding operation can perform in safe and stable condition.

c) Since the restraint becomes large in many cases at welding joints, measures including sufficient remaining heat, use of the welding rod which is excellent in crack-proof nature, and consideration of welding sequence are to be taken into consideration to prevent the development of welding crack.

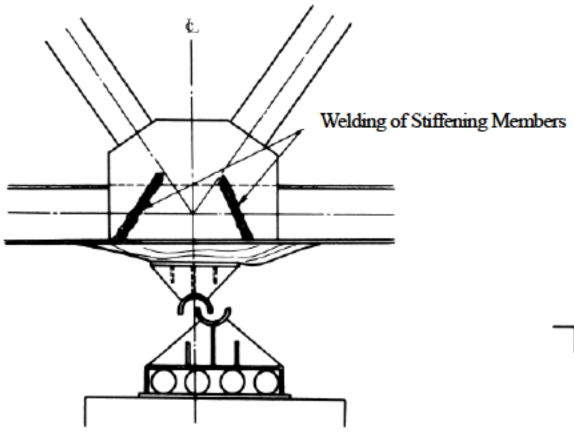


Figure 3.4.2 Installation of Stiffening Members (Example 1:Welding of Rib)

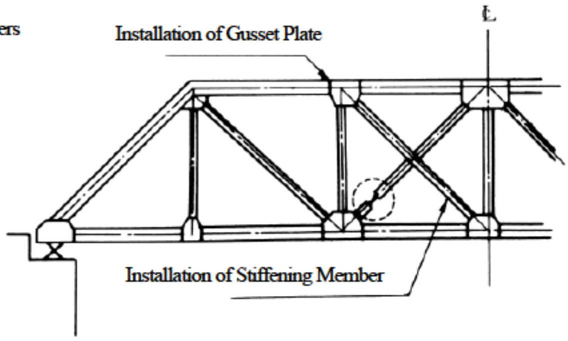


Figure 3.4.3 Installation of Stiffening Members (Example 2:Installtion of Stiffening Member)

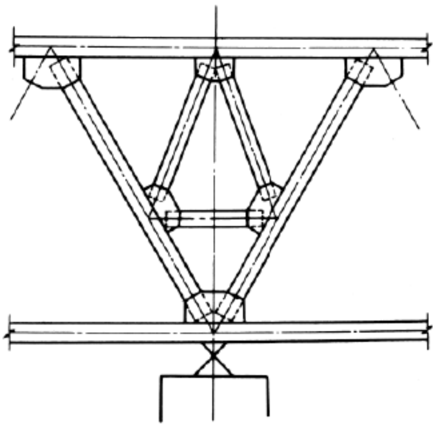


Figure 3.4.4 Installation of Alternative Members

4) Simple Unseating Prevention Measures

When there is a possibility of unseating of girders caused by the movement of girder, or damage to bearings or seat concrete, unseating prevention structures are installed to avoid the vulnerability of unseating (**Figure 3.4.5 - Figure 3.4.7**).

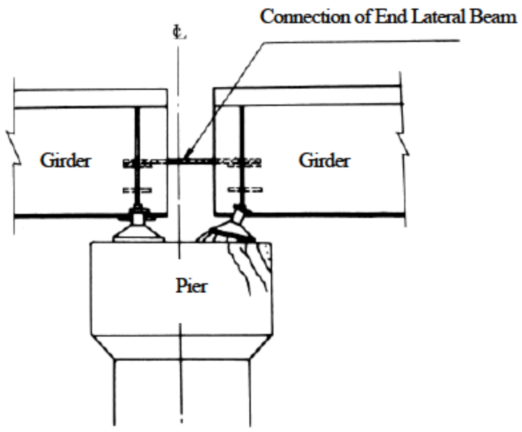


Figure 3.4.5 Unseating Prevention Device
(Example 1: Connection of Adjacent Girders)

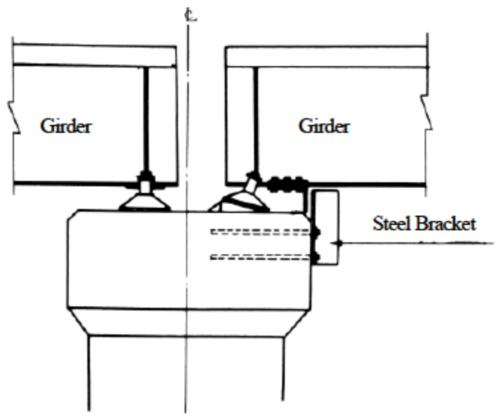


Figure 3.4.6 Unseating Prevention Device
(Example 2: Stopper)

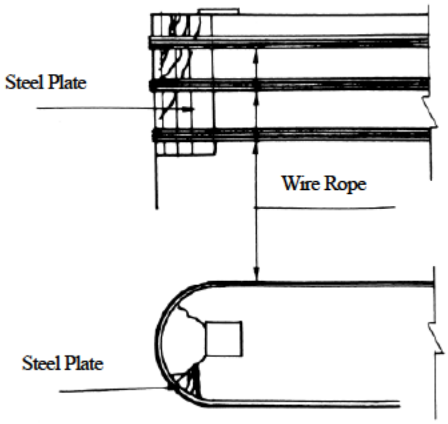


Figure 3.4.7 Unseating Prevention Device
(Example 3: Temporary Tensioning of Damaged Cap Beam)

5) Temporary Support of Girders

When there found the damage to substructures which leads to the significant reduction of residual strength capacity or the large residual displacement, the damage to superstructures which leads to reduction of bearing capacity, the damage of large displacement of girders or subsidence at bearings, and the damage to bearings or seat concrete which leads to unseating of superstructures by aftershocks, the superstructures are to be supported by temporary supports or jacks (**Figure 3.4.8** and **Figure 3.4.9**).

In addition to the above temporary supports of girders, the temporary supports for cap beams were provided in the case of the Hanshin Expressway which suffered serious damage over the whole route in the 1995 Hyogo-ken-nanbu Earthquake (**Photo 3.4.2**). This is because since there were general roads in parallel under the damaged elevated bridges, the unseating was to be prevented more surely. Moreover, there was an example in which the emergency measure by using steel plates and concrete filling was carried out to the damaged section of the reinforced concrete bridge piers (**Figure 3.4.10**) and an example in which the vertical rib was welded to the section of compression buckling at the base of steel bridge piers (**Photo 3.4.3**).

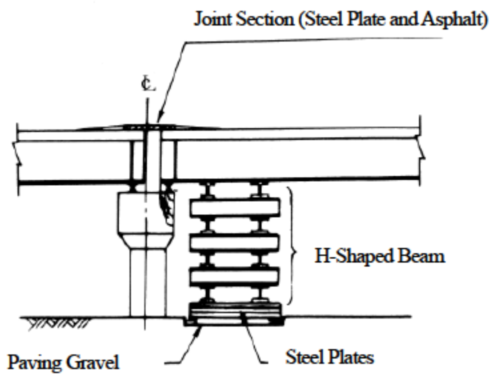


Figure 3.4.8 Temporary Support of Girder (Ex.1)

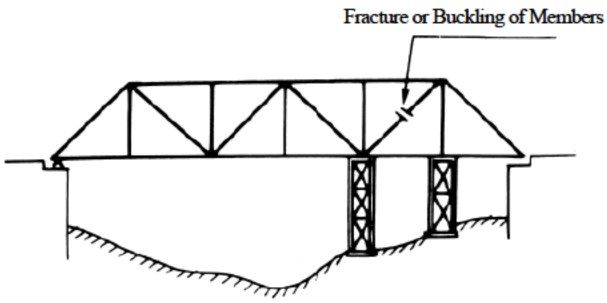


Figure 3.4.9 Temporary Support of Girder (Ex.2)

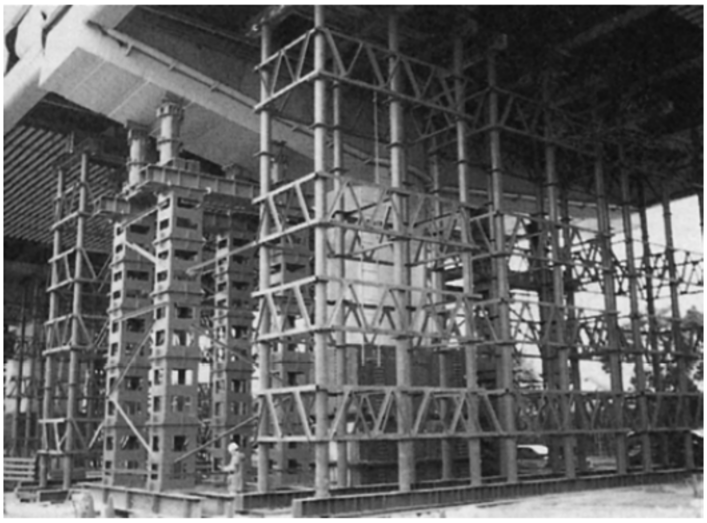


Photo 3.4.2 Temporary Supports for Girders and Cap Beams

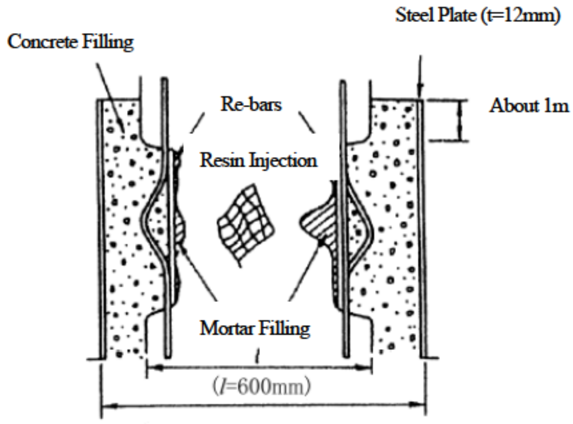


Figure 3.4.10 Emergency Measure for Damaged Section of Reinforced Concrete Piers

Photo 3.4.3 Emergency Measure for Buckling Section of Steel Piers

(3) Temporary Repair Method for Safety Reservation of Passing Vehicles and Pedestrians

For the cases in which the damage degree on passage was evaluated as a (Closure) and b (Passable with care) caused by the damage including road surface level difference, opening and breakage of expansion joints, and damage or deformation of safety barrier for vehicles, the temporary repair works are performed for the safety of passing vehicles and pedestrians, by selecting appropriate methods from the following measures.

1) Bridge Surface Covering

When there is road surface level difference, or excessive opening or breakage of expansion joints, road surface restoration is performed by the installation of plates, placing asphalt, welding of steel plate (steel expansion joints) to secure the safety of passing vehicles (**Figure 3.4.11**).

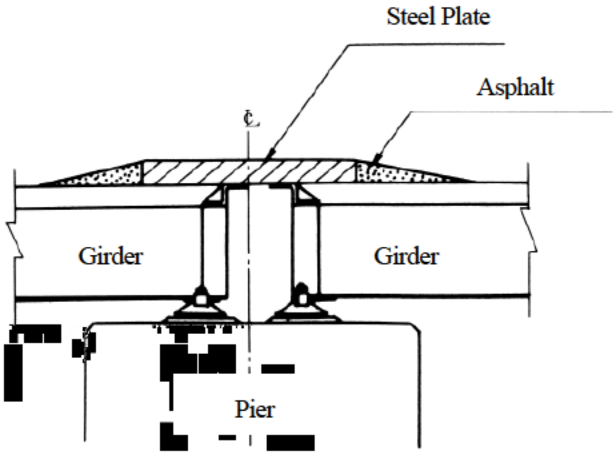


Figure 3.4.11 Road Surface Measure

2) Correction of Level Difference

When level difference occurs at the road surface by damages to bearings such as the pull-out of rollers, the correction of level difference is performed by temporary supports of girders using jacks and saddles and the passability is secured. When the settlement is developed at approaching embankment, the restoration is made by placing asphalt and macadam filling (**Figure 3.4.12**).

3) Restoration of Safety Barrier for Vehicles with Single Pipes

When the safety barrier for vehicles is damaged or broken, single pipes are installed to restore the safety barrier for vehicles temporarily (**Figure 3.4.13**).

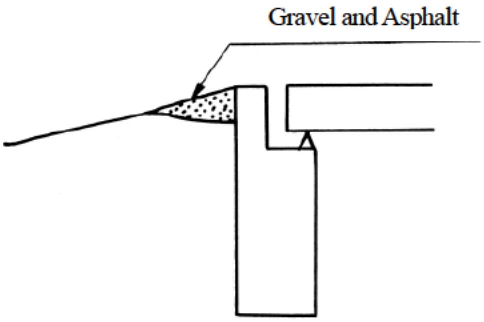


Figure 3.4.12 Correction of Level Difference

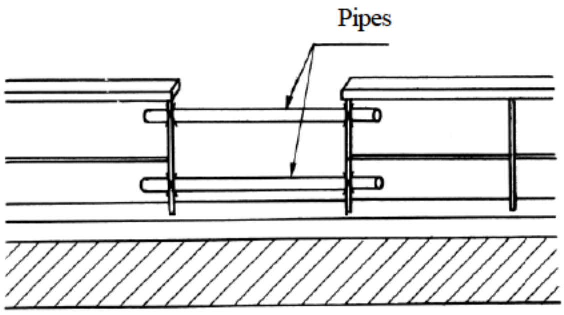


Figure 3.4.13 Repair of Safety Barrier for Vehicles

4) Safety Monitoring System

In order to temporary open to the traffic on the important roads, the safety monitoring system can be applied. **Figure 3.4.14** shows an example for the system used during the 1995 Hyogo-ken-nanbu Earthquake. The relative displacement between superstructure and substructure was monitored by the laser sensor and when any abnormal movement was observed, the system transmitted the information to drivers and road administrators.

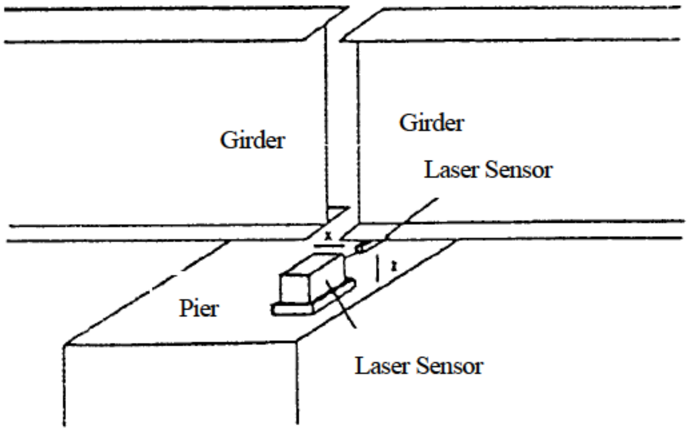


Fig 3.4.14 Automatic Displacement Monitoring System

4. PERMANENT REPAIR AND RESTORATION FOR BRIDGES

4.1 General

The objective of permanent repair is to assure the long term bridge function and bearing capacity based on the detailed inspection of damage. The inspection points of the permanent repair and the methods are basically the same as those for the temporary repair. Although to assure temporary function recovery and to prevent significant damage progress are the points for the temporary repair, to assure the long term bridge function and bearing capacity are important for the permanent repair. In the permanent repair, it is recommended to investigate the damage causes and then to select the appropriate repair methods which satisfy the required performance for the damaged bridge.

4.2 Inspection for Permanent Repair

The permanent repair method can be selected based on the concept of the repair level as shown in **Figure 2.2.1**. The detailed inspection issues which are necessary for the permanent repair are shown in the followings.

(1) Foundation

a) If there is the possibility of the residual displacement at foundation, it is necessary to make clear the residual displacement by the measurement.

b) When the residual displacement of foundation is significant, it is recommended to investigate the damage causes by excavating the surrounding soils and to review the repair methods if necessary.

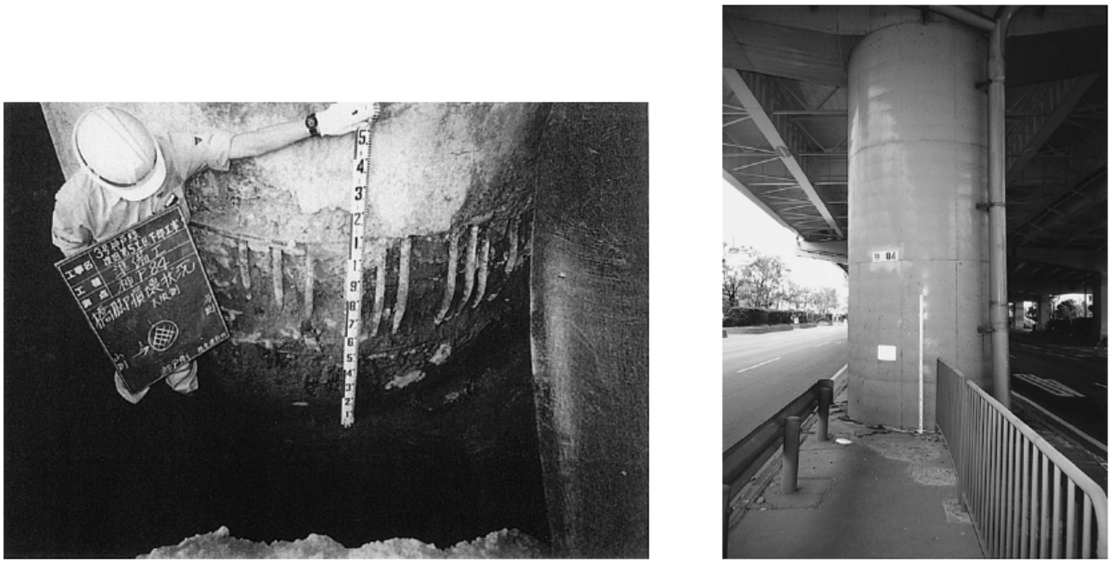
c) If there is significant deformation of surrounding soils caused by liquefaction, it is necessary to make boring surveys and the results should be reflected to the permanent repair.

d) It is necessary to investigate the scouring around the foundation and the presence of any barriers such as buried pipes in the construction area.

(2) Pier

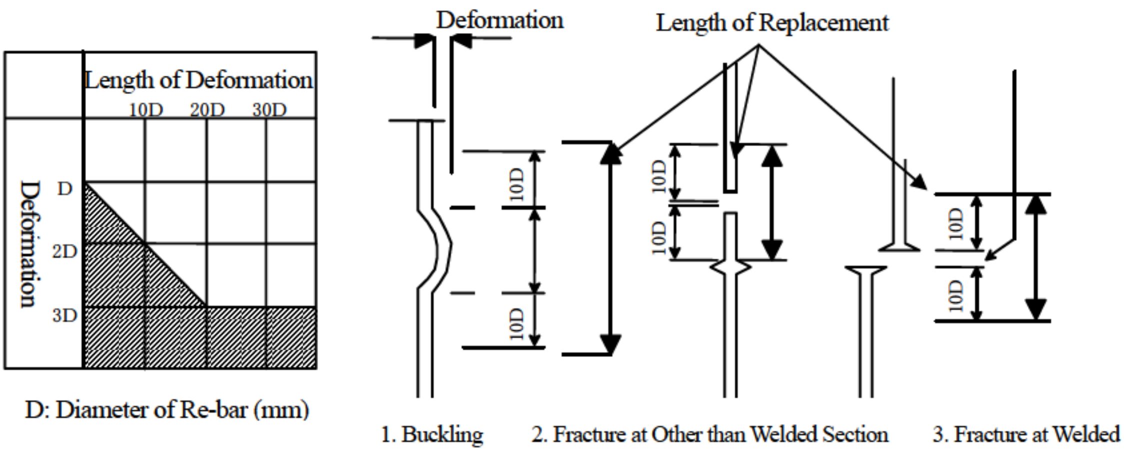
If the damage under the ground is newly observed by excavating surrounding soils, the damage degree should be checked and the results should be reflected to the repair construction (**Photo 4.2.1**). If there is residual tilting of piers, there is a possibility that it affects the passage function of bridge. When the residual tilting is significant, it is necessary to remove the damaged pier and to repair by new construction. Therefore, it is recommended to measure the residual tilting, horizontal and vertical displacement of the top of pier, then to select the repair method based on these measured data. In the repair works for the Hanshin Expressway Route #3 during the 1995 Hyogo-ken-nanbu Earthquake, the criteria of the reuse/reconstruction depending on the tilting was assumed as the value of residual angle of 1 degree.

The deformed re-bars at the damaged section are re-used when the deformation is not significant and the deterioration of re-bar performance is less. **Figure 4.2.1** shows the criteria to re-use or replace of deformed re-bars. It was used during the 1995 Hyogo-ken-nanbu Earthquake. When the deformation exceeds 3 times of diameter of re-bar, the re-bar should be replaced. And it is less than 3 times of diameter of re-bar, the deformed re-bar is replaced depending on the range of deformation.



(a) Damage under the Ground (b) Damage over the Ground

Photo 4.2.1 Damage of Pier Base under the Ground



(a) Criteria of Replacement of Deformed Re-bar (b) Length of Replacement

Figure 4.2.1 Replacement of Damaged Re-bars

(3) Abutment

It is recommended to inspect the collision between girder and parapet wall, the crack or damage at the bottom of parapet, and the damage of wings. The results should be reflected to the permanent repair method. As the same as for piers, the residual tilting and damage under the ground should be inspected and the results should be reflected to the repair methods.

(4) Superstructure

The damage is developed mainly around the bearing or the girder ends of superstructures. For steel girders, it is necessary to inspect in detail the location and the extent of local buckling. This is to judge the necessity to remove the concrete slab, to cut and remove a part of girder, and the possibility of recovery to the original by heating. When there is residual displacement at foundation, pier and abutment, it is recommended to check the effect on the superstructure.

(5) Bearing Support

When the bearing is restored by full replacement, it is recommended to inspect the possibility of re-use of existing anchor bolts, the space for jack up, the necessity of strengthening of girder, and appropriate seat width to resist lateral seismic force.

(6) Unseating Prevention Device

When an unseating prevention device is replaced or newly installed, it is recommended to select the appropriate type of unseating prevention device based on the detailed inspection of structural characteristics including arrangement of girder, deck end lateral girder, parapet of abutment, and width of top of substructure.

(7) Expansion Joint

Since the expansion joint is a member which is installed at the boundary between adjacent girders, it is easily affected by the relative displacement. Therefore, it is recommended to inspect the expansion gap and damage of joints including face plate, joint rubber and anchor concrete.

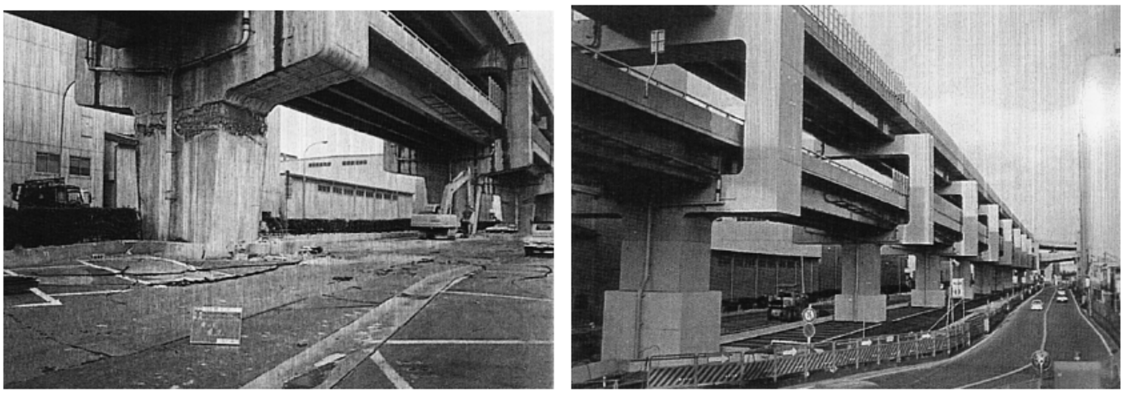
4.3 Compilation of Inspection Results

The inspection results should be compiled for the effective application for permanent repair works. It is recommended to make them as database, damage and repair report for the preparation of future maintenance and retrofit works.

4.4 Permanent Repair Method

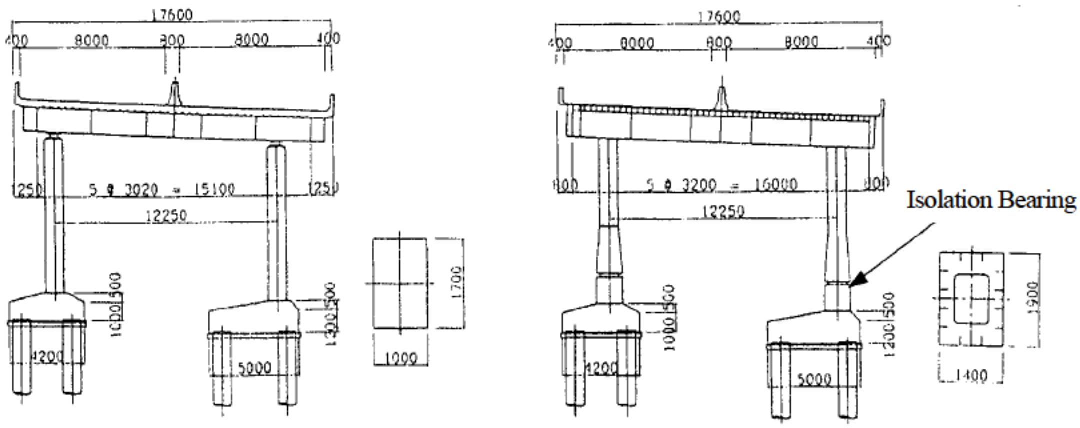
Based on the evaluation of damage degree, the basic concept for permanent repair is classified into "Not needed," "Repair to the Original," "Improvement of Strength," and "Structural Modification." "Repair to the Original" is to repair as the same function of the original structure using the same structure and materials. On the other hand, "Structural Modification" is to restore with the enhancement of seismic performance by structural modification. "Improvement of Strength" is to repair with upgrade of strength of the same structure.

When it is not feasible to repair in view from the technology and economical reason such as a case that the damage degree depending on the bearing capacity is judged as A (Critical damage), the restoration method that the damaged bridge is removed and new bridge is constructed can be selected. When it is difficult to re-use the original structure, the restoration method by structural modification can be selected. **Photo 4.4.1** shows an example using structural modification method in which the damaged reinforced concrete piers were replaced by the steel piers. **Figure 4.4.1** shows another example. The original 19 spans continuous flame bridge was restored by using seismic isolation system in which the isolation devices were installed at the bottom of columns.



(a) Before Restoration (b) After Restoration

Photo 4.4.1 Restoration Example by Structural Modification



(a) Before Restoration (b) After Restoration

Figure 4.4.1 Restoration Example by Structural Modification

The permanent repair and restoration method is recommended to be selected widely considering construction period, cost, constructionablity, procurance conditions of materials and equipments, and outside scenery. When the permanent repair method with the concept of the structural modification and the improvement of strength is selected, the possibility of influence of such modification and/or strengthening should be investigated.

In the 1995 Hyogo-ken-nanbu Earthquake, there were many cases where the construction in safety and in a short time was required in the restricted space. There were the cases where the superstructure was re-used as it was and only bridge piers with the high damage degree had to be removed and reconstructed.

Moreover, depending on the future plan of the affected area or the damage grade of the area and the route, the plan including the restoration which improves the value of the bridges concerned, such as improvement in traffic function, environmental condition, and scene, in addition to the earthquake-proof safety, may be needed. The example is shown in **Figure 4.4.2**.

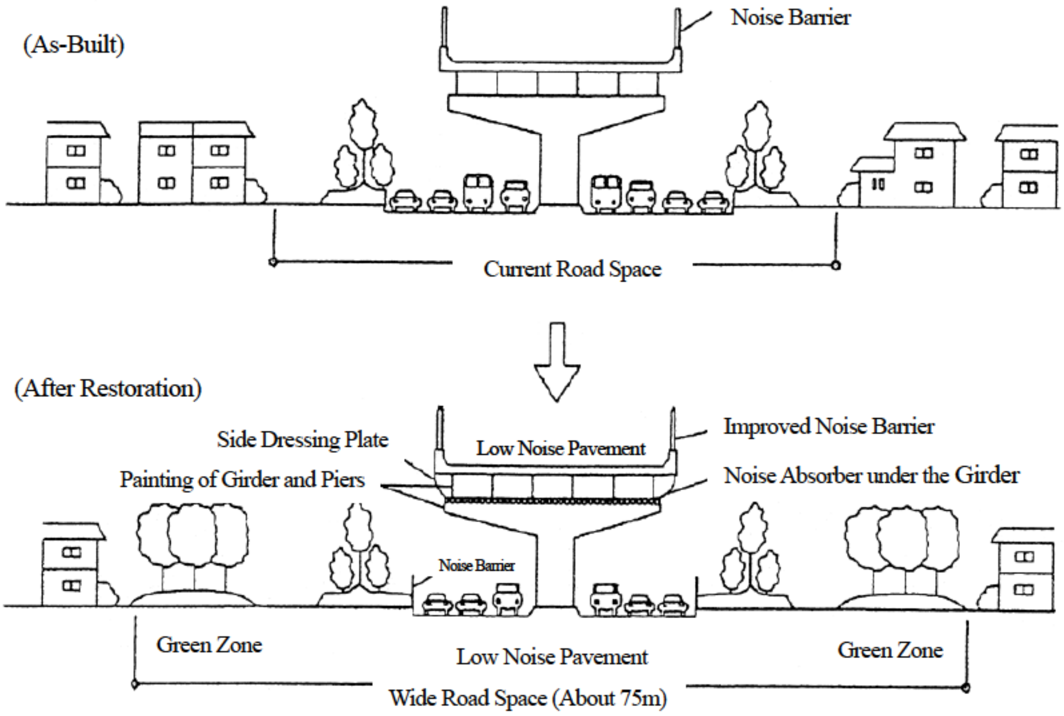


Figure 4.4.2 Improvement Plan of Traffic Function

When selecting the restoration method, the necessary construction period, the cost of construction, the constructionability, the supply conditions of materials and machines, and the scene are taken into consideration comprehensively. However, since these conditions change with not only the damage situation of the bridge concerned but the countermeasure situations of the surrounding area, it is important to select a proper construction method synthetically in consideration of these. Moreover, when the restoration is made to aim at structural change or improvement of strength, it is required to examine the influence on the whole structural system. In addition, since there is not necessarily an established method to evaluate the residual strength of damaged structures, the evaluation of damaged members should be made considering safety of the whole structural system in many cases.

(1) Foundation

As the repair and restoration methods for foundations, there are two methods in which the damaged foundation is removed and new foundation is constructed, and the enhancement of seismic performance of existing foundation.

In general, it is not easy to remove existing foundation, then the existing foundation is re-used as much as possible and the repair and restoration method to enhance seismic performance is selected. When the residual displacement of foundation is observed, it is necessary to investigate the effect on the piers and superstructures.

The followings are typical permanent repair methods for foundations.

1) Adding of New Piles and Footing

A method to enhance seismic performance of foundation by increasing the bearing capacity by adding new piles and enlargement of footing

2) Construction of Underground Walls and/or Beams

A method to enhance seismic performance of foundation by increasing the bearing capacity by constructing the underground walls and beams

3) Construction of Sheet Piles

A method to enhance seismic performance of foundation by increasing the bearing capacity by constructing the sheet piles

4) Soil Improvement

A method to enhance seismic performance of foundation and resistance against liquefaction by increasing the bearing capacity by soil improvement

5) Foot Protection

A method to enhance seismic performance of foundation with scouring by constructing foot protection

6) Replacement

A method to remove existing foundation and to construct new foundation with necessary seismic performance

The above is a list of general repair and restoration methods for damaged foundations. The followings are the examples employed during the 1995 Hyogo-ken-nanbu Earthquake, in which, the foundations were damaged by the effect of significant liquefaction and lateral spreading in Osaka bay area.

1) Adding of New Piles and Footing

The method was applied for the foundations which were affected by the liquefaction and lateral spreading in the reclaimed area to enhance the stiffness and strength of foundations by adding new piles (**Figure 4.4.3**).

2) Soil Improvement

The method was applied for the foundations which were affected by the liquefaction and lateral spreading in the reclaimed area to enhance the stiffness and strength of foundations by constructing blocking wall. The wall was constructed by drilling using high-pressure air and water and by filling the curing materials. The wall was constructed up the depth of non-liquefiable layers (**Figure 4.4.4**).

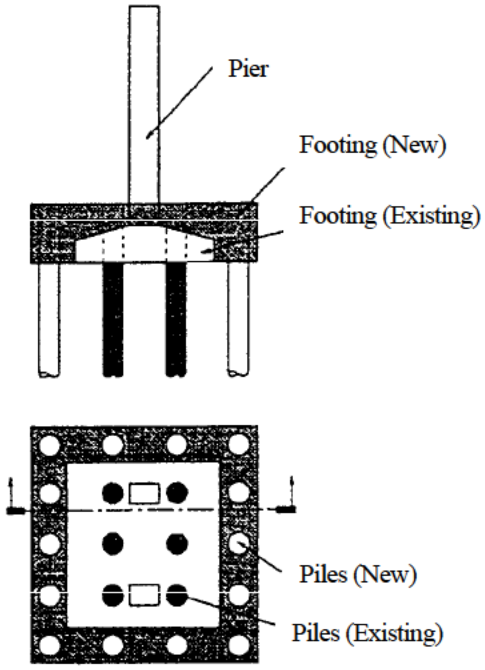


Figure 4.4.3 Increasing Number of Piles to enhance Seismic Performance of Foundation

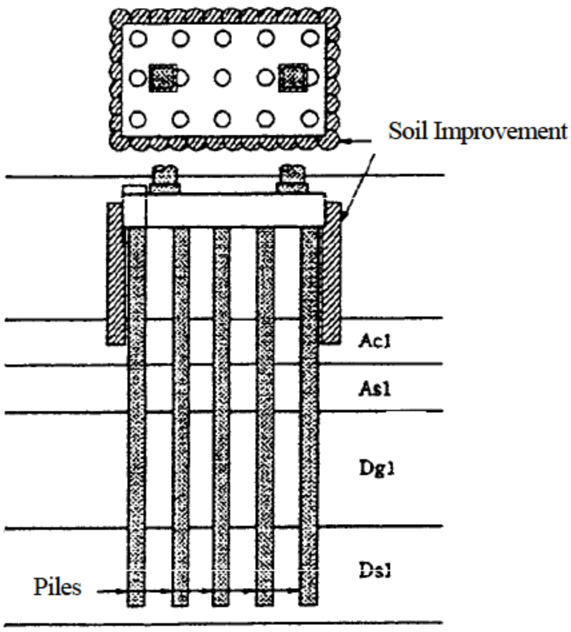


Figure 4.4.4 Soil Improvement to prevent the Effect of Soil Liquefaction of Surrounding Soils

3) Crack Injection Method

The core boring was made for the damaged piles from the footing and the crack was injected by filling materials. The method was employed for the foundation in which the damage was medium and the strength of the foundation satisfied the required one (**Figure 4.4.5**).

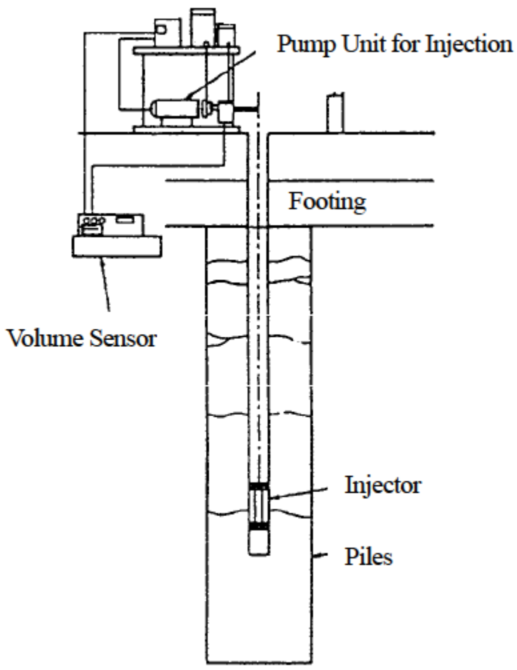


Figure 4.4.5 Crack Injection Method

(2) Reinforced Concrete Piers

The repair methods for reinforced concrete piers can be selected from **Table 4.4.1** depending on the damage situation and damage degree.

The material mechanical characteristics of damaged reinforced concrete piers for the repair design can be assumed as **Table 4.4.2** depending on damage degree. The method was applied for the repair designs of Hanshin Expressway Route #3 after the 1995 Hyogo-ken-nanbu Earthquake. In the repair works, it was necessary to remove damaged separated concrete, to inject to cracks, and to replace deformed re-bars. For the case of damage degree was equal or greater than A (Critical damage) and such repair methods were not feasible, there was a case in which the complete removal of the damaged section and the reconstruction was necessary.

Table 4.4.1 Permanent Repair Methods for Reinforced Concrete Piers

Degree / Damage Situation (Damage Degree)		As: Near Collapse	A: Critical Damage	B: Medium Damage	C, D: Slight Damage	
Damage at Base of Column	Damage shown in **Table 3.3.6**	1. and Large Tilting	1.	2.	3.	4. 5. 6.
	Repair Method	• Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Fiber Sheet Jacketing	• Resin Injection
Damage at Cut off Section of Longitudinal Re-bar	Damage shown in **Table 3.3.7**	1.	2.	3.	4. 5.	6. 7.
	Repair Method	• Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Fiber Sheet Jacketing	• Resin Injection
Damage in Shear	Damage shown in **Table 3.3.8**	1.	2.	3.	4.	5. 6.
	Repair Method	• Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Installation of Seismic Wall • Removal and Reconstruction	• Reinforced Concrete Jacketing • Steel Plate Jacketing • Installation of Seismic Wall	• Reinforced Concrete Jacketing • Rebar Anchor • Stressing • Fiber Sheet Jacketing	

Table 4.4.2 Material Characteristics of Damaged Piers

Damage Degree			B	C	D
Allowable Stress Check	Young's Modulus of Re-bar		$2/3E_s$	$2/3E_s$	E_s
	Concrete	Allowable Compression Stress	$0.8\sigma_{ca}$	σ_{ca}	σ_{ca}
		Allowable Shear Stress	$0.7\tau_{al}$	τ_{al}	τ_{al}
Ductility Check	Yield	Young's Modulus of Rebar	$2/3E_s$	$2/3E_s$	E_s
		Compression Stress of Concrete	σ_{ck}	σ_{ck}	σ_{ck}
	Ultimate	Young's Modulus of Rebar	E_s	E_s	E_s
		Compression Stress of Concrete	σ_{ck}	σ_{ck}	σ_{ck}
		Shear Stress carried by Concrete	$0.7\tau_c$	τ_c	τ_c

Note) E_s: Young's Modulus of Rebar of Existing Members ($2.0x10^5 N/mm^2$)

σ_{ck}: Design Strength of Concrete of Existing Members

τ_{al}: Allowable Shear Strength of Concrete of Existing Members

τ_c: Allowable Shear Stress of carried by Concrete of Existing Members

1) Resin Injection and Repair Section (Repair by Resin Putty, Mortar, and Concrete)

When the crack or some peeling of cover concrete is developed even though the strength deterioration is small, the resin injection can be used for crack repair, the peeing of cover concrete can be repaired by placing resin putty, mortal and concrete. **Figure 4.4.6** shows an illustration of injection methods that is effective for not only enhancement of the long term durability but also the strength recovery. If it is necessary to minimize the reduction of stiffness of repaired piers, it is recommended to use the high Young's modulus material or the resin with coarse aggregates. **Figure 4.4.7** shows a pre-packed method in which the resin is injected to the section with aggregate and forms, that can be used for piers with smaller section.

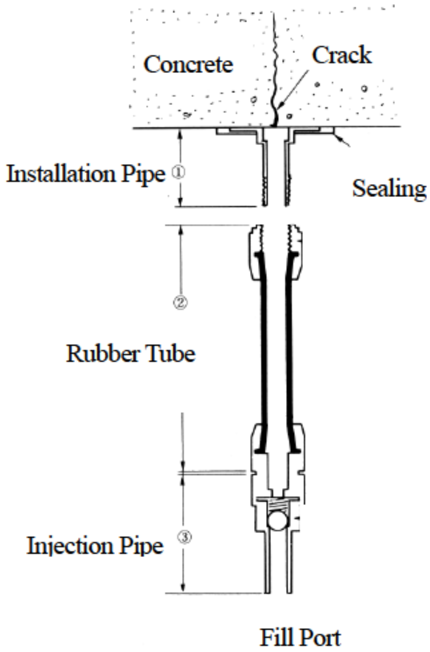


Figure 4.4.6 Example of Injector

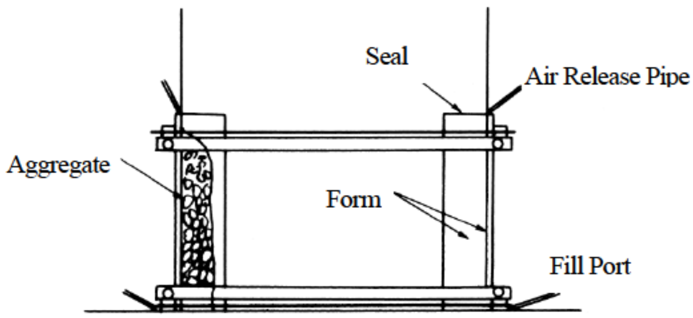


Figure 4.4.7 Pre-packed Method

2) Reinforced Concrete Jacketing

The method is to jacket the damaged column with relatively heavy damage and significant reduction of strength in reinforced concrete, in order to enhance the strength and ductility (**Figure 4.4.8**). The method is one of general and effective methods to increase the strength of damaged piers.

To increase bending strength of piers by reinforced concrete jacketing, the longitudinal re-bars are anchored to the footing. It is recommended to treat the existing concrete surface by such as tipping and to add and arrange the connection re-bar for the enough integration between new and existing concrete.

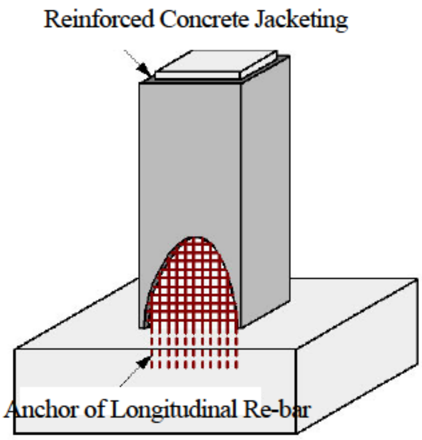


Figure 4.4.8 Reinforced Concrete Jacketing

3) Steel Plate Jacketing

The method is to jacket the damaged column by steel plate, in order to enhance the shear and bending strengths and ductility (**Figure 4.4.9**). The method is effective for the piers with restriction to increase the size of pier section. When the bending strength is increased, anchors are necessary to connect with steel plate and footing. For the steel plate jacketing method, attentions should be paid to the bending fabrication detail and welding conditions.

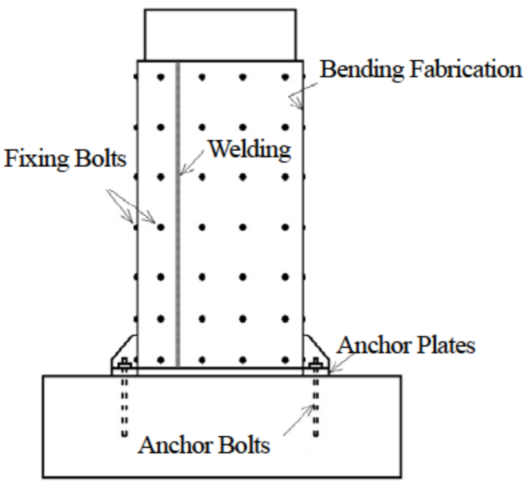


Figure 4.4.9 Steel Plate Jacketing

4) Combined Method of Reinforced Concrete and Steel Plate Jacketing Method

The repair method was applied for the restoration of the bridge piers which suffered from the damage degree of B (Medium damage) or less which were damaged by the 1995 Hyogo-ken nanbu Earthquake. The construction method is to aim at earthquake resistant improvement by reinforced concrete jacketing. Since the lateral tie re-bars in the existing bridge pier section were not enough, the steel jacketing is made after the reinforced concrete jacketing to enhance shear strength and confinement effect (**Figure 4.4.10**).

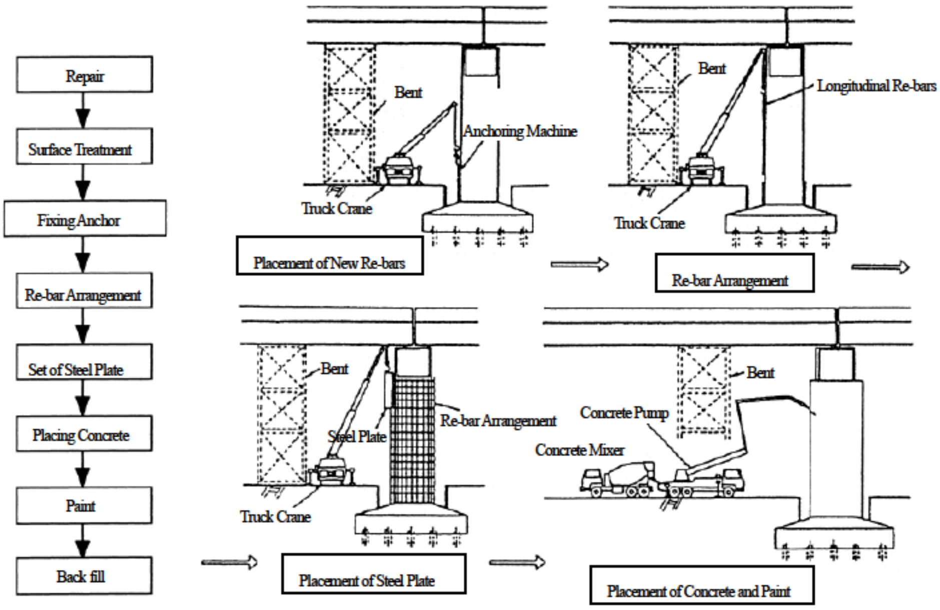


Figure 4.4.10 Combined Method of Reinforced Concrete and Steel Plate Jacketing Method

5) Fiber Sheet Jacketing

Advantages of fiber sheet are high strength, light material and high constructionability because of the light weight. Therefore, the method is effectively employed for the sites with restricted conditions such as limitation of construction space. On the other hand, it is necessary to think about details such as connection with footing in order to increase the bending strength, and the protection covering methods against deterioration and impact.

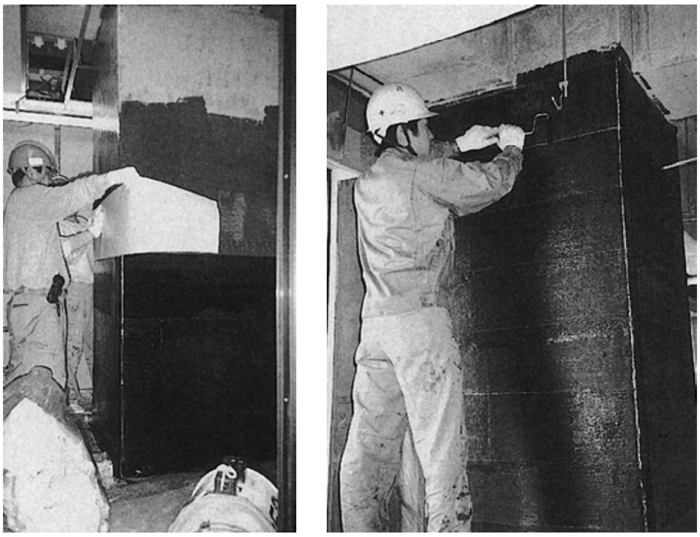


Photo 4.4.2 Construction Situation of Fiber Sheet Jacketing

6) Stress Introduction

The methods are applied for the piers with significant large cracks and residual displacement, the strength is recovered by introducing the stress in the column (**Photo 4.4.3**). The method has been used to close the cracks or to prevent the development of cracks caused by drying shrinkage and creep. The method is used with concrete jacketing, strengthening effect is also expected. Against development of shear cracks, the shear strength can be recovered by introducing the stress.

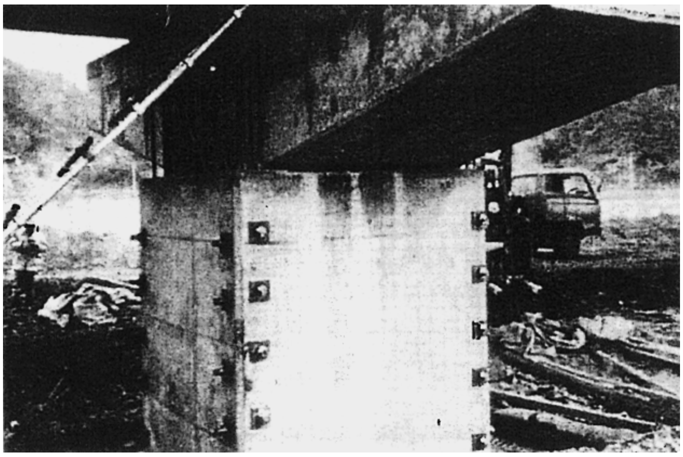


Photo 4.4.3 Stress Introduction

7) Construction of Seismic Wall

When a flame type pier is damaged in the transverse direction, the strength is recovered by adding the seismic wall with the repair of damaged columns and beams (**Figure 4.4.11**). There are many examples of verification tests in building area, and it is reported that the strength is improved greatly. Moreover, it is reported that the resin anchors or mechanical anchors are applicable to fix the steel rod to existing members (**Figure 4.4.12**).

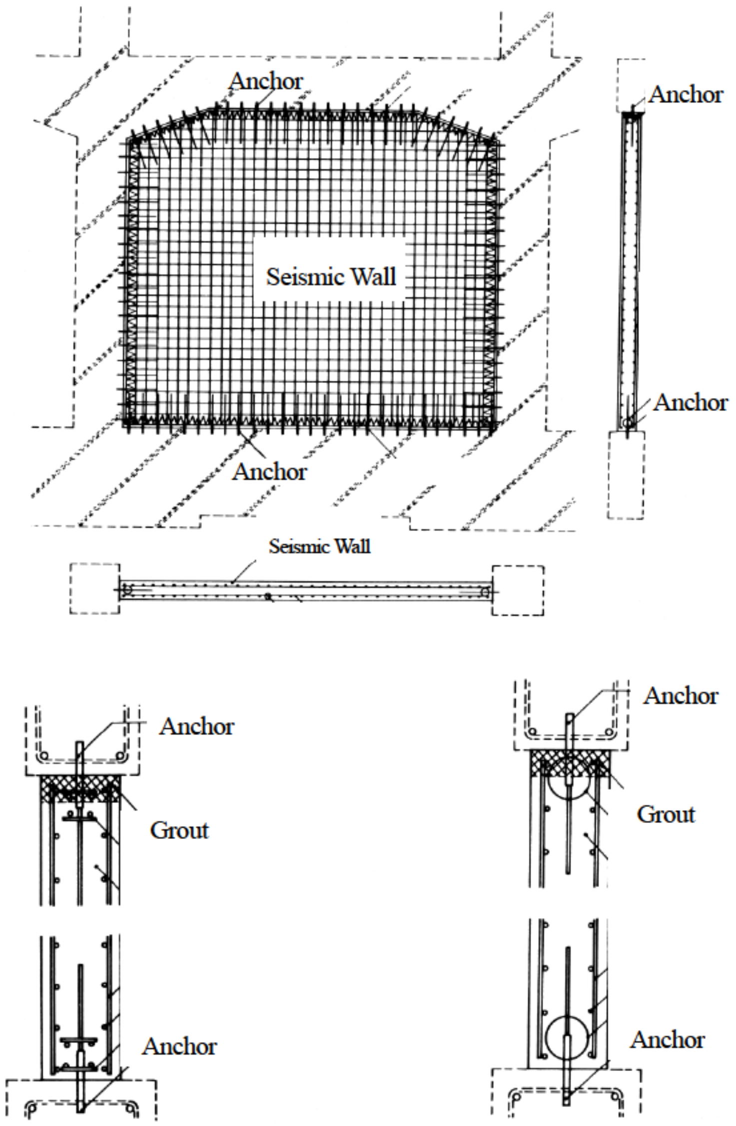
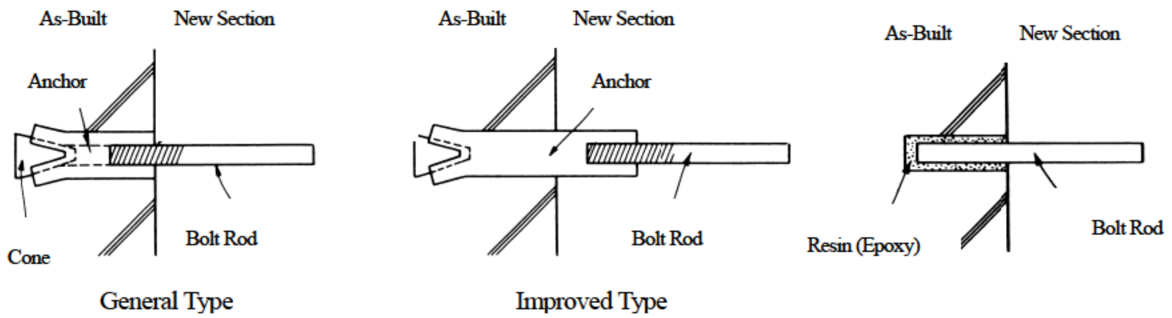


Figure 4.4.11 Construction of Seismic Wall into Frame Type Pier



(a) Mechanical Anchor (b) Resin Anchor

Figure 4.4.12 Examples of Embedded Anchors

8) Removal and Reconstruction

A bridge pier is replaced when the damage is remarkable and the restoration is difficult to be done. When the strength of footing decreases by fixing longitudinal steel re-bars to the footing for the restoration of piers, the increase of thickness of the footing is also to be carried out (**Figure 4.4.13**). Moreover, when the weight of bridge pier increases by the restoration, it is necessary to consider the influence of the increase of dead loads on the foundation, and to also aim at earthquake performance improvement in the foundation if needed (**Figure 4.4.14**).

The above presents the general restoration methods. The restoration method adopted during the 1995 Hyogo-ken-nanbu Eearthquake is shown in the following.

For the Hanshin expressway Route No. 3 Kobe line, the bridge piers which suffered a destructive damage near collapse (damage degree of A_s and A) was removed at the base, and the bridge piers were newly reconstructed. The outline is shown below.

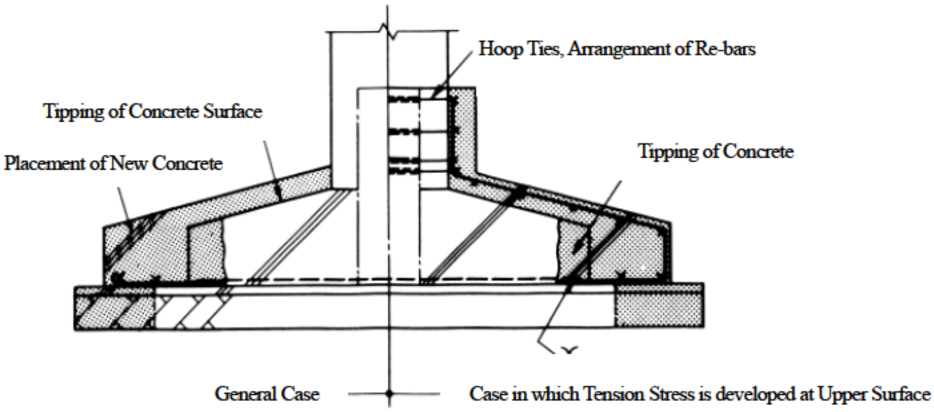


Figure 4.4.13 Earthquake Performance Improvement by Enlargement and Thickening of Footing

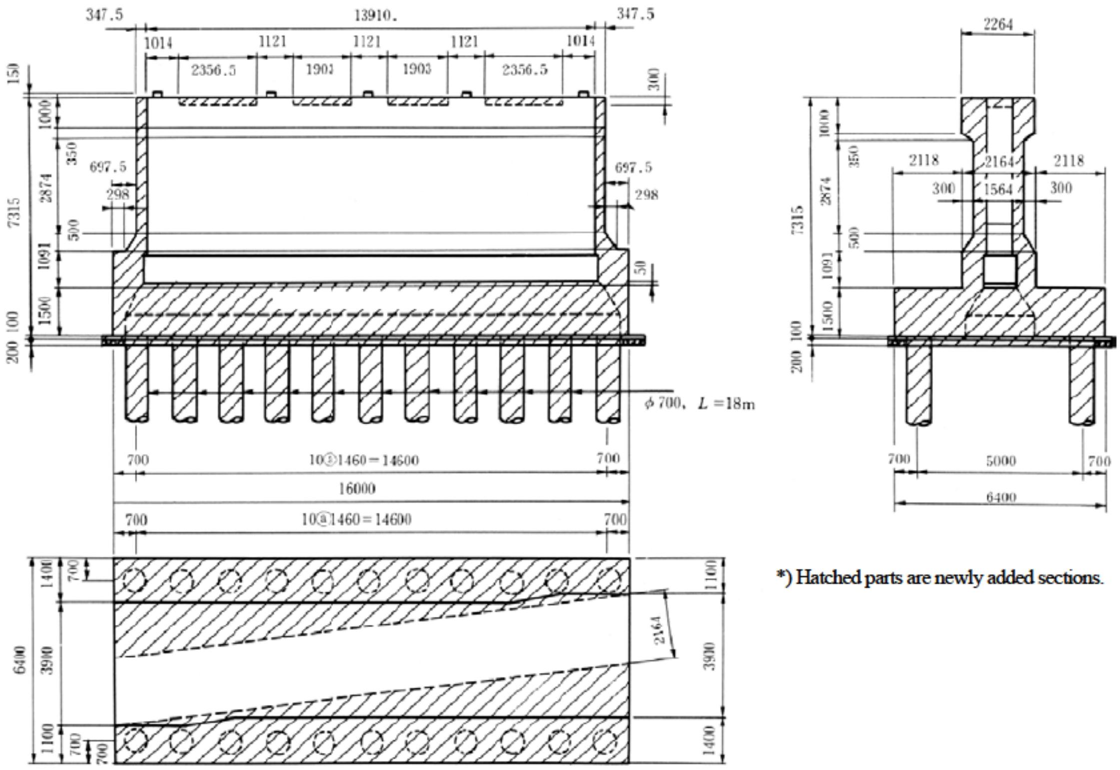


Figure 4.4.14 Earthquake Performance Improvement by Reinforced Concrete Jacketing, Enlargement of Footing and Installation of Additional Piles (In case in which the Strength of Column and Bearing Capacity of Foundations are insufficient)

a) Removal Method

There was a section where the bridge pier was required to be removed under the conditions that the superstructure remained as built. The following removal methods were adopted depending on the damage situation and construction conditions.

i) Removal Method using Large-size Crane

It is a general method that the reinforced concrete piers are cut to the block with the weight of about 20tf which can be carried, and is removed using a large-sized track crane and crawler crane. The method is adoptable in the situation where the superstructure is already removed (**Figure 4.4.15**).

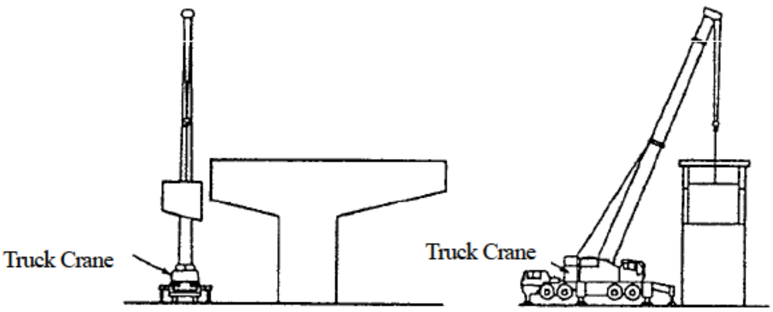


Figure 4.4.15 Removal Method using Large-size Crane

ii) Removal Method using Telpher Crane

It is a method in which the removed blocks are hanged down to the ground using Telpher crane. This method is comparatively simple manufacture assembly, and is suitable for the case in which the space under the girder is restricted. Since expansion space is used, it is adoptable for the bridge piers which support simple girders (**Figure 4.4.16**).

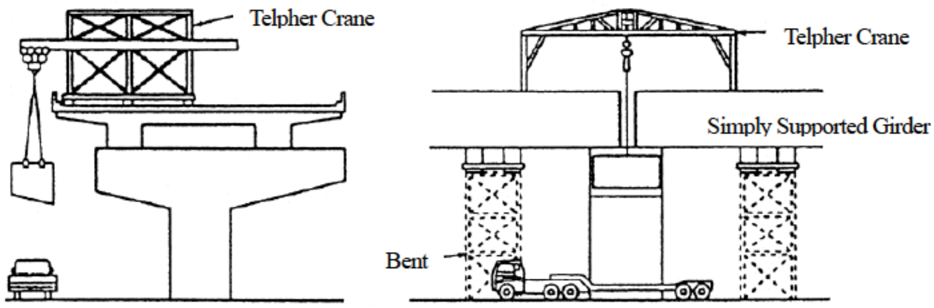


Figure 4.4.16 Removal Method using Telpher Crane

iii) Removal Method using Super Large-size Jack

Super large-size jack is an equipment which generally lifts and carries the super weight large-sized things at the plant in a factory or a port. It is a method in which the jack is installed under the beam, and removed block is jacked down to the ground. On the occasion of removal of piers, the removal method by hanging is adopted. In addition, the rail is provided under the jack and the blocks are moved to the position which can be shipped by self-movement system. The method is suitable to remove the middle piers of continuous girder bridges under the condition to leave the girder as built (**Figure 4.4.17**).

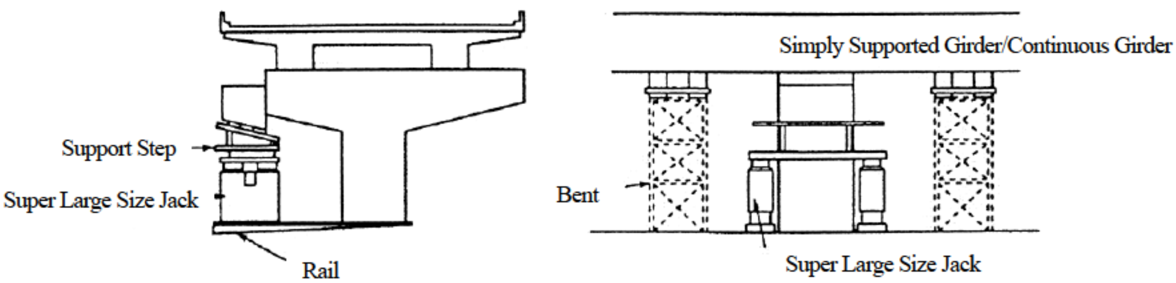


Figure 4.4.17 Removal Method using Super Large Size Jack

iv) Removal Method using Self-propelled Large-size Truck

Self-propelled large-size truck is a carrying device of super-weight large-sized thing as the same as super large-size jacks. When it is used for the removal of bridge piers, the self-propelled large-size truck with the vent mount is made to enter under the girder, and the vertical movement mechanism of the wheels is used, removed large block is supported and taken out. Since the center of gravity at the time of taking out becomes high and unstable, it is important to make the center of gravity lower using suitable counterweights, or to fully fix removed block with vent mount. It is the method which is suitable for the removal of the middle bridge pier of a continuous girder under the condition in which the girder remains as built (**Figure 4.4.18**).

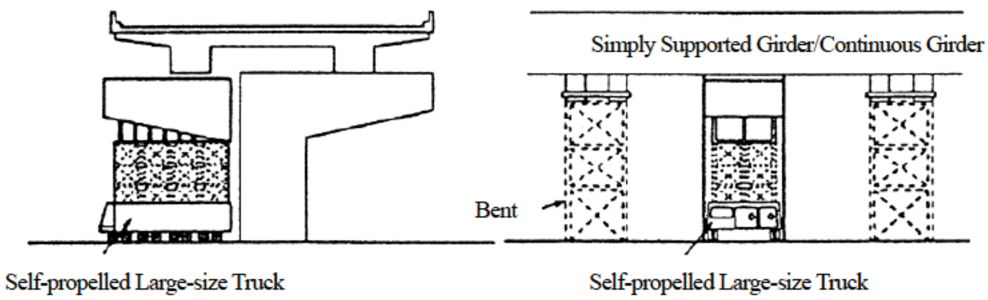


Figure 4.4.18 Removal Method using Self-propelled Large-size Truck

b) Reconstruction Method

Reconstruction of bridge piers is to construct new piers on the existing footing and foundations. New re-bars are connected with existing ones at the bottom, and additional new re-bars to increase the flexural capacity of piers are installed surrounding existing re-bars with anchoring to the footing, and then the concrete is placed. Furthermore, by arranging the lateral ties surrounding longitudinal re-bars densely, the horizontal confined effect and the improvement in shear strength are expected. The weight saving and the reduction of construction time can be made by the adoption of steel beams (**Figure 4.4.19**).

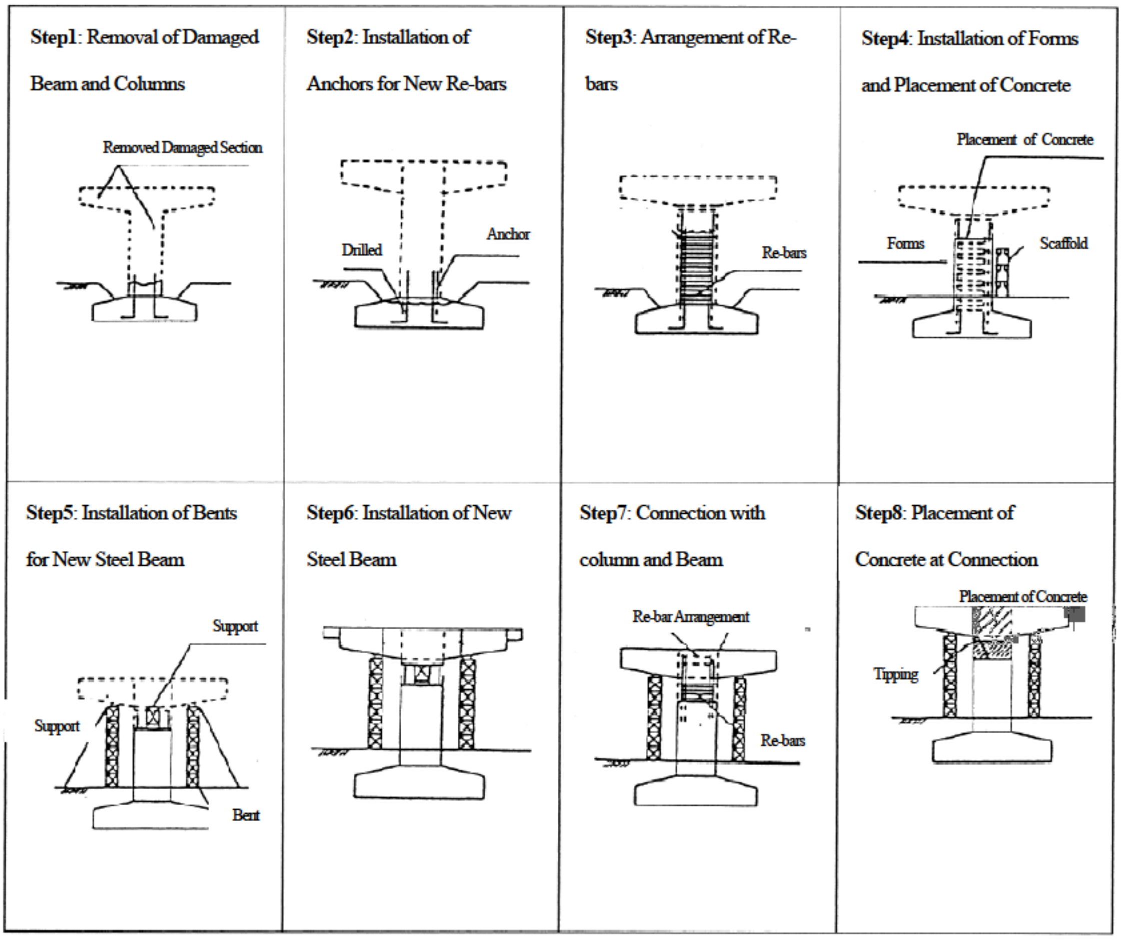


Figure 4.4.19 Reconstruction Method of Reinforced Concrete Piers

(3) Abutment

1) Abutment Wall

The repair methods for reinforced concrete piers can be applied for abutment wall as well. Since the abutment is subjected to soil pressure, it is recommended to construct sheet piles for earth retaining if necessary.

2) Parapet and Approach Bank

Based on the judgment of damage degree, the appropriate method can be selected from the followings.

a) Reconstruction of Parapet

b) Construction of Supporting Plate between Abutment and Backfill Soil

The settlement is developed at backfill soil, the supporting plate is effective to prevent the same type damage.

(4) Superstructure

Based on the inspection for the permanent repair, the appropriate repair methods should be selected in the followings.

1) Concrete Girder

The repair methods for reinforced concrete piers basically can be applied for concrete girders as well. In the past earthquake, damage is developed at the girder ends around bearing supports and the repair methods are shown in the followings.

a) Repair by Resin Mortar and Resin Injection

The cracks are filled by cement or mortar. To enhance the strength at the cracks, injection of epoxy resin or resin mortal can be applied.

b) Steel Plate Attachment

The method is to attach the steel plate to girder by anchor bolt and epoxy resin. Depending on the attachment method, there are floating method and injected floating method.

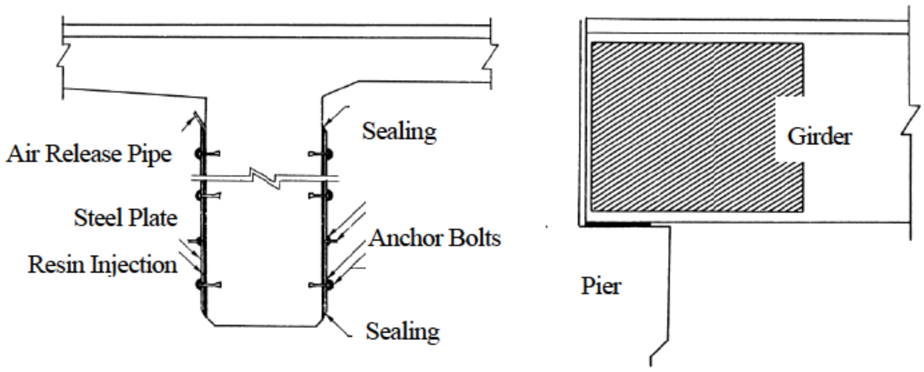


Figure 4.4.20 Steel Plate Attaching Method for Concrete Girder

2) Steel Girder

There are five typical seismic damage modes on steel girders, in general, such as torsion deformation, fracture of members, deformation of members, cracks of members, and cut of connection bolts.

a) Torsion Deformation

The torsion deformation of superstructure is developed caused by the displacement of substructures. The unbalance or uplift may be developed at the bearings and affect the traffic if the effect is significant. The repair methods can be as follows.

i) Adjustment of the height of seat concrete to make balance at bearing supports (**Figure 4.4.21**)

ii) Lateral beams are once removed, the deformation is adjusted, and then the lateral beams are installed again. Or, the superstructure should be reconstructed.

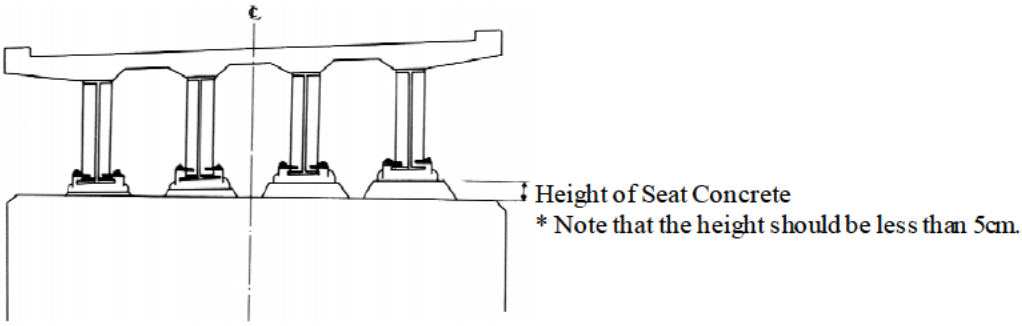


Figure 4.4.21 Repair Method for Superstructure by Adjusting Height of Seat Concrete

b) Fracture of Members

The appropriate repair method should be selected depending on the importance of damaged members. The damage of primary members such as upper and lower truss members leads to the possibility of unseating of superstructure. The permanent repair method is full replacement of damaged members if possible. If it is not possible, the reconstruction of superstructure is necessary. The repair methods for the secondary members such as lateral members or load distribution members should be selected considering the structural role of damaged members.

c) Deformation of Members

The deformation of members can be classified into buckling and deformation of bar members and plate members. The replacement is a general repair method for bar members, but plate members are repaired by heating reformation methods (**Figure 4.4.22** and **Figure 4.4.23**). When the developed deformation is significant, the deformed section is removed and replaced by new section with the construction of temporary supports of superstructure.

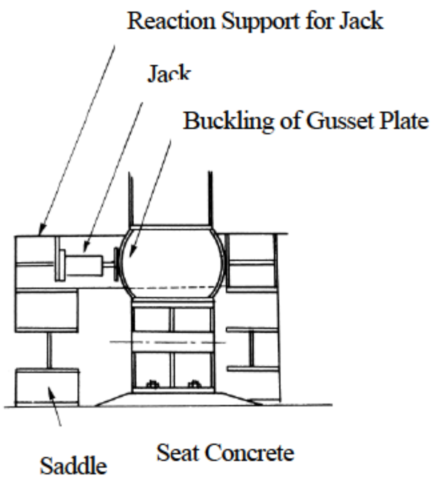


Figure 4.4.22 Reformation by Heating

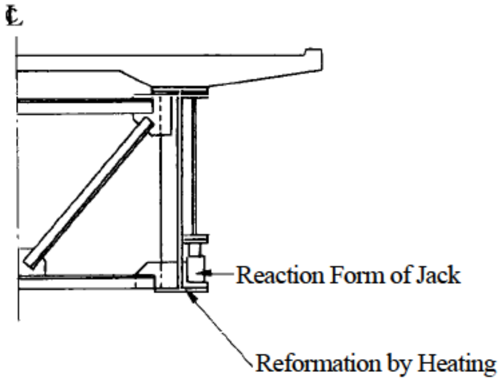


Figure 4.4.23 Reformation by Jacks

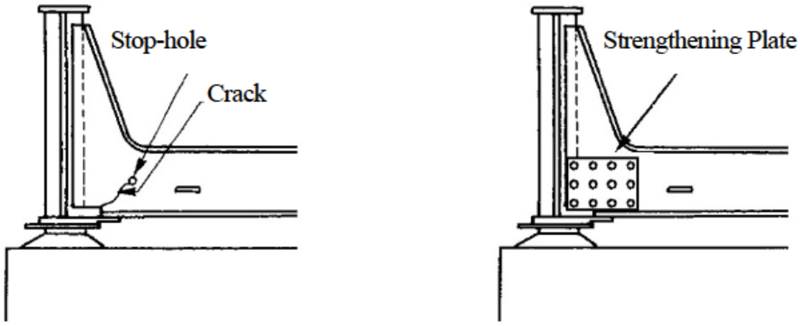
d) Crack

There are several repair methods for the crack of steel member depending on the damage cause. **Figure 4.4.24** shows one of the repair methods in which the stop-hole is provided at the edge of the crack to stop the progress and the plate is installed and connected by bolts. When the stop-hole is provided around stress concentrated section and welded section, attention should be paid to stress distribution and location of holes so as to prevent the development of new cracks. It should be noted that when the stop-hole is made, attention should be paid not to make unnecessary macula around the holes.

There is a method to install strengthening plate so as to be able to check the progress of cracks. **Figure 4.4.24(2)** shows an example that the stop-hole can be checked by appropriately connecting the steel plate.

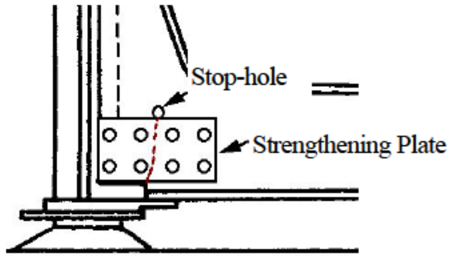
e) Cut of Rivet and Bolt

It is recommended to replace rivets to new bolts when rivets were cut. Even when one rivet was cut, it is better to replace all bolts on one connecting plate or gusset plate. This is because to prevent the mixing use of different type of bolts at the same connection (**Figure 4.4.25**).



(a) Installation of Stop-hole (b) Strengthening Plate is Installed

(1) Strengthening Plate is bolted over Stop-hole



(2) Strengthening Plate is bolted so as to be able to check Progress of Crack

Figure 4.4.24 Strengthening by Steel Plate Connection

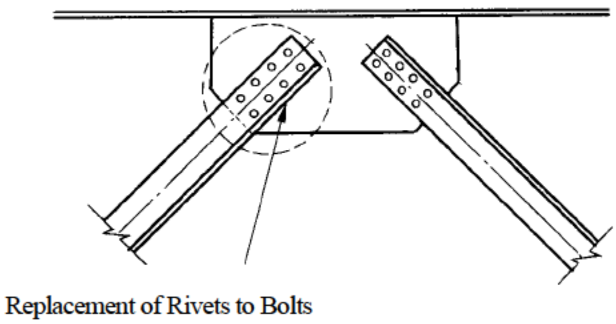


Figure 4.4.25 Bolt Connection

3) Displacement of Superstructure

The basic concept of the repair method for the displacement of girder is just to shift the girder to the original position. The location of girder is adjusted by using jacks, the damaged bearings are repaired or replaced, and the expansion joints are repaired (**Figure 4.4.26**).

When it is difficult to restore the bridge by shifting the girder because of the residual displacement of substructures, there is an example to relocate the bearing supports without shifting of the girder.

There are two methods for the relocation of bearing supports, they are a method to shift the location of upper shoe, and a method to shift the location of lower shoe.

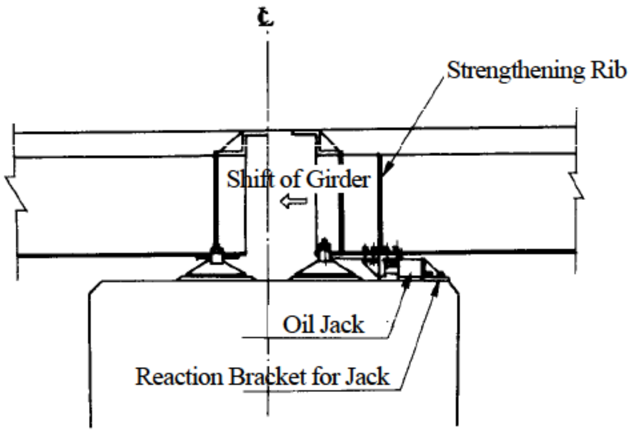


Figure 4.4.26 Shift of Displacement of Girder

a) Relocation of Upper Shoe

The girder is temporary supported and the damaged bearing is removed, and new bearing is installed with adding stiffener if necessary (**Figure 4.4.27**). It is easier to relocate upper shoe than lower shoe because the widening is sometimes required for the relocation of lower shoe. But for truss bridge, the relocation of upper shoe is generally difficult because the location of connection section of truss members is shifted from the force point, then there is a possibility that the bending force is applied to truss members.

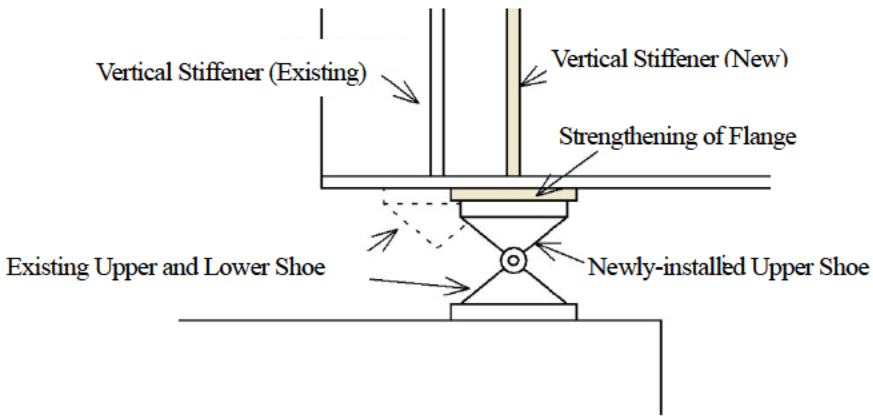


Figure 4.4.27 Repair Method by Relocation of Upper Shoe

b) Relocation of Lower Shoe

The superstructure is temporary supported, damaged bearings are removed then new anchor bolts and bearings are installed. If necessary, seat width is increased (**Figure 4.4.28**).

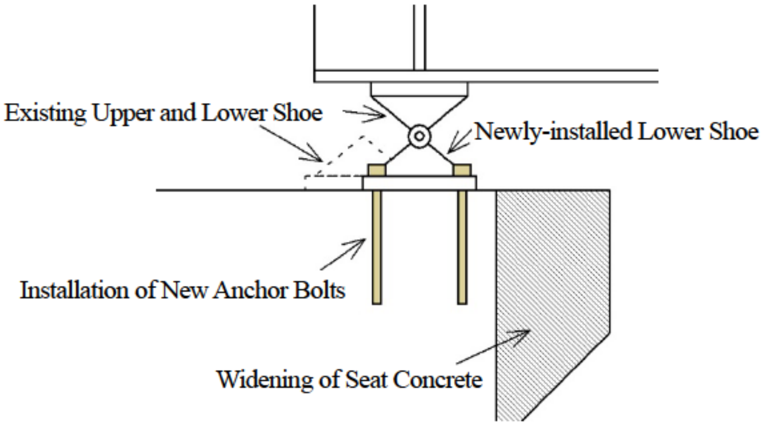


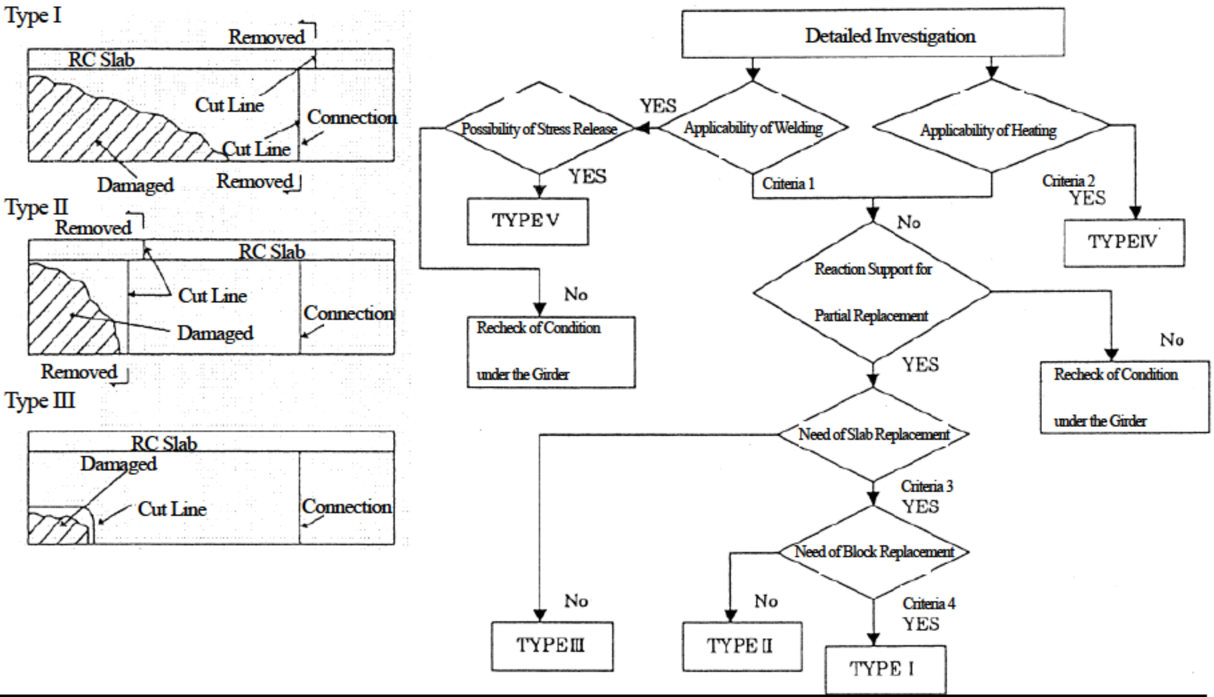
Figure 4.4.28 Repair Method by Relocation of Lower Shoe

4) Settlement of Bearing Support

When the cause of settlement of bearing support is the damage of bearing itself, the damaged bearing is removed and new bearing is installed. On the other hand, when the cause is settlement or tilting of substructures, there is a method to adjust the height of bearing with consideration of the long term stability. When the height is adjusted by increasing the thickness of seat mortar, the mortar is more vulnerable to fail to seismic effect. When it is greater than 5cm, the reinforced concrete seat block should be placed.

5) Restoration Method of Steel Girders adopted by 1995 Hyogo-ken-nanbu Earthquake

On the Hanshin expressway route No. 3 Kobe line, the unseated simple girders and heavily buckled continuous girders which caused by the damage to bridge piers was removed, and the girders were reconstructed by the steel floor system in consideration of the weight saving. In addition, the damage to the girder ends or bearing support sections occurred for many steel girders. The damage was classified according to the flowchart shown in **Figure 4.4.29** and the repair methods shown in **Table 4.4.3** were selected.



Repair Criteria

Criteria 1 :(Partial Replacement of Crack Damage) Crack damage without deformation is repaired by welding.

Criteria 2:(Partial Replacement of Deformed Section) Deformation is repaired by heating correction when the minimum inside radius r_{min}>15t(t: thickness).

Criteria 3: (Removal of Floors Slab) Removal of floor slab is avoided as much as possible.

Criteria 4: (Replacement by Block) Replacement by block unit when the cut section of steel girder is longer than half of block length.

Figure 4.4.29 Repair Methods of Damaged Steel Girders

Table 4.4.3 Repair Methods of Damaged Steel Girders

Type	Repair Methods
Type Ⅰ	Floor concrete placing after removing damaged sections per block with removal of the floors, and connecting new blocks with high tensile bolts.
Type Ⅱ	Floor concrete placing after removing the floors, cutting and removing damaged sections, and connecting new components with high tensile bolts.
TypeⅢ	New components connection with high tensile bolts after cutting and removing damaged sections without the removal of floors.
TypeⅣ	Heating reform without cutting and removal of damaged sections.
TypeⅤ	Welding without cutting and removal of damaged sections.

(5) Bearing Support

Damage of bearing supports can be repaired depending on the damage sections as shown in the followings.

1) Bearings

a) Repair of Deformation and Damage of Bearing and Sole Plate

When the bearing and sole plate were deformed and damaged, in general, the bearing and sole plate is replaced. (**Figure 4.4.30** and **Figure 4.4.31**)

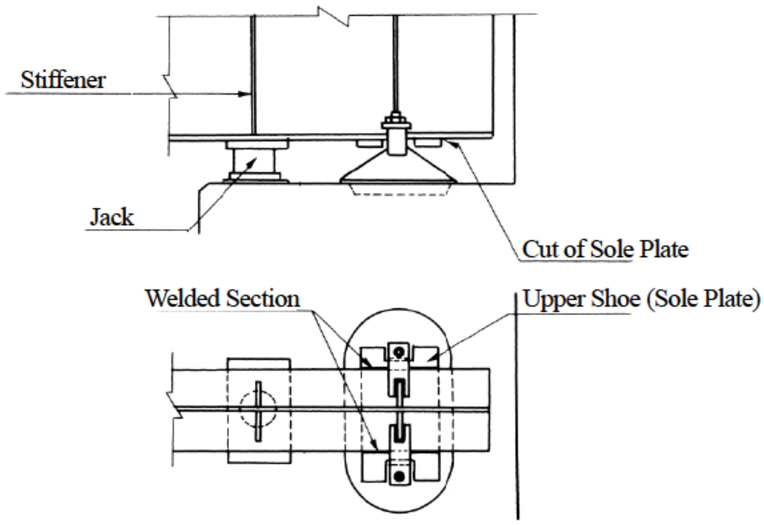


Figure 4.4.30 Replacement of Upper Shoe

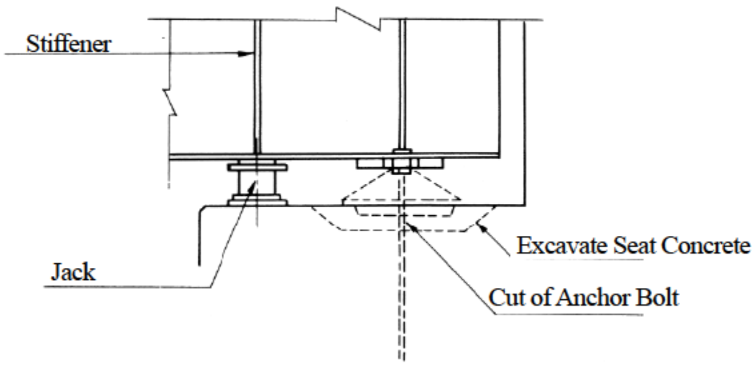
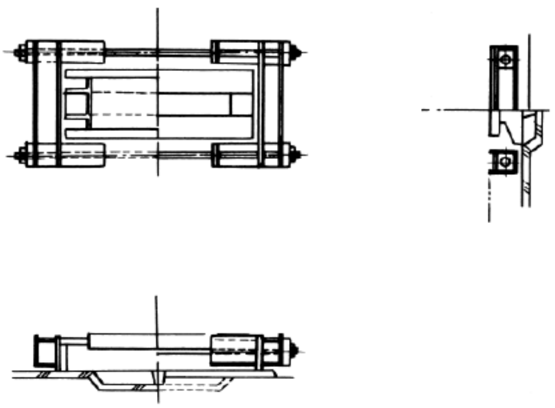


Figure 4.4.31 Replacement of Lower Shoe

b) Repair of Deformation and Damage of Stopper

When there is deformation or damage to stoppers including of upper shoe stopper, side blocks and anchor re-bars, the stopper is replaced or new alternative structure is installed. The anchor steel bars are cut and new bolts are welded and restored. Since there is some work space on abutments or bridge piers in case of steel bridges, and it is comparatively easy to replace the damaged bearings. On the other hand, in case of concrete bridges, it is also possible to use jacks for the lift-up of girders, but since there is no jack space at the girder, the replacement of the upper shoes component is generally difficult. For this reason, it is restored in many cases with installation of displacement stoppers (**Figure 4.4.32** and **Figure 4.4.33**).



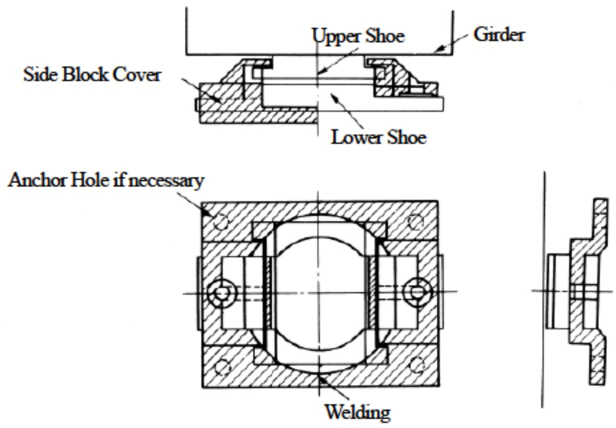


Figure 4.4.32 Installation of Reinforced Frame (Example 1)

Figure 4.4.33 Installation of Reinforced Frame (Example 2)

c) Repair of Pull-out, Deformation and Fracture of Anchor Bolt

When there is pull-out, deformation or fracture at anchor bolts, the bolts are repaired by replacement, or cut of damaged bolts and welding of new bolts.

d) Repair of Loosing or Fracture of Set Bolts (Pin Type Bearing and Roller Bearing)

When there is the loosing or fracture of set bolts, the repair is made by the replacement. For the slight loosing, the repair is made by washer insertion and retightening.

e) Repair of Pull-out of Pin Cap and Damage of Pin (Pin Type Bearing and Roller Bearing)

When there is the pull-out of pin cap or fracture of pin, the repair is made by the replacement. It is better to use just a little smaller size pin, in order to secure the function of the pin.

f) Repair of Pull-out of Roller or Rocker (Roller Bearing and Rocker Bearing)

When there is pull-out of roller or rocker, the repair is made by the replacement of roller or rocker, or total replacement of the bearing.

g) Repair of Deformation and Fracture of Uplift Stopper

When there is the deformation or fracture at the uplift stoppers such as side plates, the repair is made by the replacement. In addition, when the damage is remarkable or the repair is difficult, the repair is made by replacement of the whole bearings.

h) Repair of Deformation and Fracture of Rubber Bearing

When there are cracks of rubber section or large residual displacement at rubber bearings, the repair is made by the replacement of the rubber bearings or by shifting the girders by jacking up.

2) Seat Mortar

The seat mortar is constructed in order to adjust the height of bearing and to protect the bearing. When the damage to seat mortar is less than cracks, the damage is repaired by injecting resin to prevent progress of cracks. The damage to seat mortar causes the reduction of lateral strength of anchor bolts and leads to weak point in next earthquake event. Therefore, when the mortar is damaged heavily, the mortar should be replaced fully. Replacement is made by removing the damaged bearing and seat mortal, and installing bearings again then placing non-shrinkage mortar. When there is well adhesion at existing anchor bolts, existing anchor bolts can be re-used (**Figure 4.4.34 - Figure 4.4.36**).

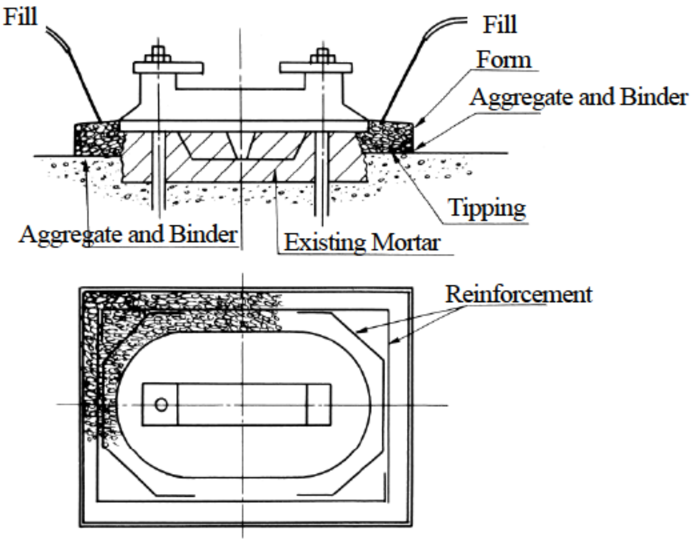


Figure 4.4.34 Replacement of Seat Mortar (Example 1: Partial Repair)

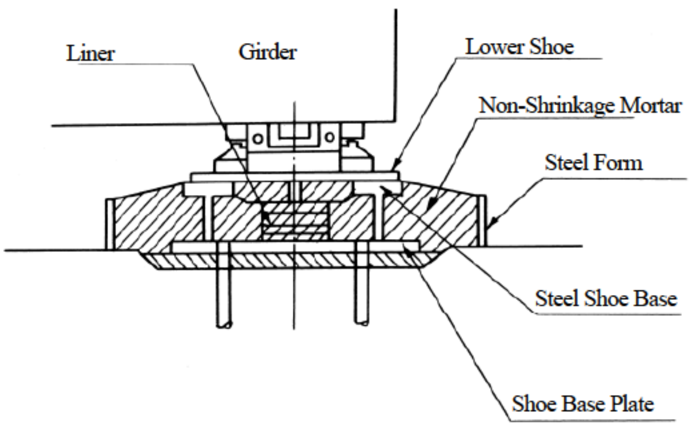


Figure 4.4.35 Replacement of Seat Mortar (Example 2: Need to be Height Change)

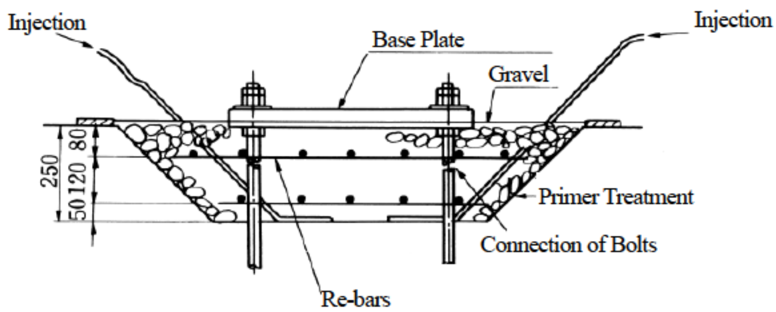


Figure 4.4.36 Replacement of Seat Mortar (Example 3: Replacement of Anchor Bolts)

3) Seat Concrete

The crack of seat concrete is generally repaired by injection of resin. When the damage is heavier, the substructure is strengthened by such as jacketing method. **Figure 4.4.37** and **Figure 4.4.38** show examples of repair method of partially damaged seat concrete. When the seat width is not enough for required seat length, it is necessary to widening the width (**Figure 4.4.39** and **Figure 4.4.40**).

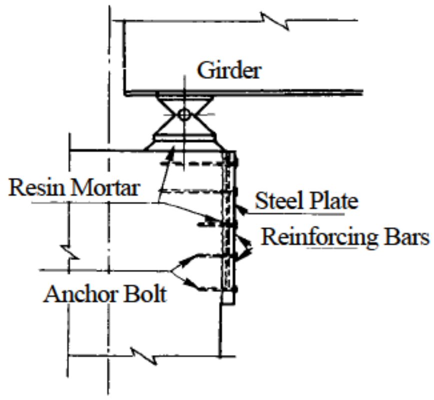


Figure 4.4.37 Steel Plate Attachment (One side Connection)

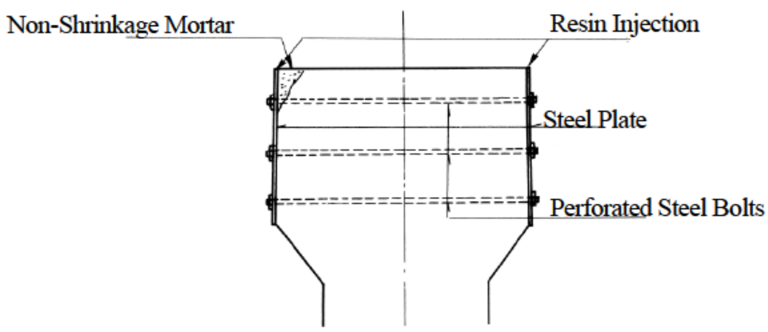


Figure 4.4.38 Steel Plate Attachment (Sandwich Connection)

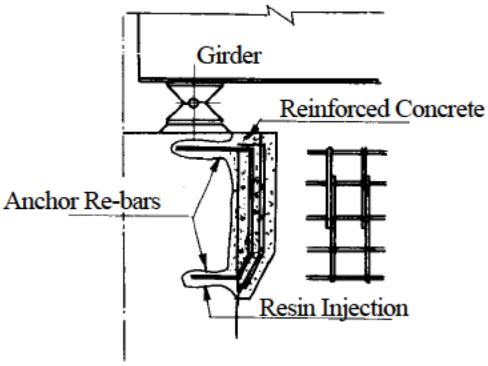


Figure 4.4.39 Widening of Seat Concrete (One side Widening)

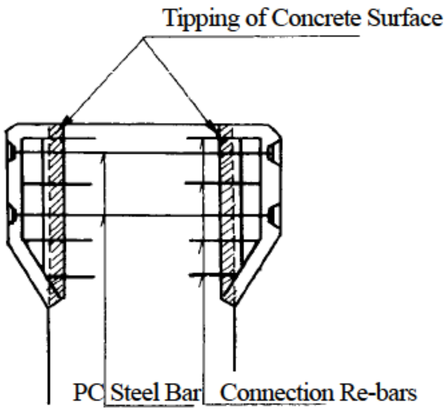


Figure 4.4.40 Widening of Seat Concrete (Sandwich Widening)

4) Unseating Prevention Devices

When bearings, end structures and bearing support sections of superstructure, and the expansion joints are damaged, there is a possibility that damage occurs also at the unseating prevention devices. It is necessary to confirm the unseating prevention devices have the predetermined strength. And it is necessary to consider the restoration including full replacement according to the restoration method of other damaged sections.

5) Expansion Joints

a) Repair for Omission of Masonry Joint Material

When there is omission of masonry joint material, the function of joints is filled up by joint material.

b) Repair for Breakage of Steel Faceplate

When there is breakage of faceplate, the function of joints is recovered by welding of the breakage part plate or replacement of the joint.

c) Repair for Fracture of Joint Rubber

When there is fracture of joint rubber, the function of joints is recovered by replacement of fracture section or replacement of whole joint.

d) Repair for Breakage of Anchor Concrete Section

When there is breakage of anchor concrete section, the function of joints is recovered by removal of damaged section and re-construction, or re-construction of the anchor concrete section.

e) Repair for Closing and Opening of Joint

When there is closing or opening at joints, the function of joints is recovered by shifting the girder or replacement of joints. In addition, attention is paid to grasp the movement of main girder movement, damage and residual displacement of substructures, and the damage to bearings which lead to closing, opening, or level difference, and then they are restored.

f) Repair for Level Difference

When there is level difference, the function of joints is recovered by repairing of bearing supports, modification of height of bearings, or replacement of joints. In addition, the damage of joints is caused in general as a result of the relative displacement of superstructures or the damage of bearings. Therefore, if the main damage factor is restored, displacement of the joint is also restored in many cases.

6) Others

When damage causes the loss of the function of damper, it is a general method to replace damaged parts or to replace whole damper system depending on the damping mechanisms of the damaged damper.

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