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DEVELOPMENT OF MANUAL FOR REPAIR METHODS FOR CIVIL ENGINEERING STRUCTURES DAMAGED BY EARTHQUAKES

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ABSTRACT

The Japanese Ministry of Construction completed a 5-year research project entitled "Development of Repair Methods for Structures Damaged by Earthquakes," in March, 1986. The purpose of this project is to develop a guideline for inspection and measurement methods, assessment methods, repair methods, and overall evaluation methods of repairing, for structures and natural slopes affected and damaged by earthquakes. This paper will describe an outline of "Manual for Repair Methods for Civil Engineering Structures Damaged by Earthquakes," which is an important part of the results of the 5-year project conducted at the Public Works Research Institute and the Geographical Survey Institute of the Ministry of Construction.

INTRODUCTION

Located along the Pacific seismic region, Japan is one of seismically disastrous countries in the world and has often suffered from large earthquakes. The recent advancement in structural and earthquake engineering, however, has enabled us to safely design and construct various civil engineering structures. As a result, catastrophic disasters due to entire collapses of buildings and structures have extremely decreased, and accordingly the numbers of human fatalities have become comparatively low during recent large earthquakes. It is considered, however, that minor damages and partial failures may still break out in future earthquakes, as observed in recent ones such as the Miyagiken-oki Earthquake of 1978 and the Nihon-kai-chubu Earthquake of 1983. In view of this fact, post-earthquake measures including the development of repair methods for partially damaged structures have become significantly important.

Basing on the above-mentioned background, the Ministry of Construction initiated a comprehensive research project entitled "Development of Repair Methods for Structures Damaged by Earthquakes," in April, 1981, and completed in March, 1986. This project is to develop post-earthquake measures by providing practical engineers with procedures of inspection and measurement, assessment of damage extent, repair methods, and overall evaluation for repairing seismically damaged structures. This paper will briefly introduce an outline of "Manual for Repair Methods for Civil Engineering Structures Damaged by Earthquakes," with emphasis on repair of road facilities.

FLOW OF REPAIR AND RESTORATION

Repair and restoration of seismically damaged civil engineering structures shall be correctly and immediately conducted because it significantly affects restoration activities of the public and stabilization of national life. Repair and restoration shall be done in accordance with the disaster plans by correctly understanding the whole damage, and by consulting and exchanging information with

related organizations and authorities. Flow of repair and restoration after the occurrence of an earthquake can be classified into three stages as shown in Fig. 1. The fundamental aims of the three stages are the following:

1) First Stage of Repair and Restoration

To inspect an outline of damages with emphasis on damages of critical facilities as early as possible, and to decide the outline of strategy for repair and restoration. When large secondary disasters are likely to happen, it is necessitated to conduct appropriate urgent treatments.

2) Second Stage of Repair and Restoration

To inspect damages of all facilities, and to judge the necessity of temporal repair and restoration with the consideration on large secondary disasters, emergency for restoration, types and importance of the facilities, and the time required for initiation of permanent restoration. When temporal repair and restoration are required, it is necessitated to quickly repair, by considering priority and restoration level.

3) Third Stage of Repair and Restoration

To determine the level required for permanent repair and restoration in view of importance, location of damage, damage degree, difficulties of repair and restoration, and future construction plan, and to conduct permanent repair and restoration by taking future development plan and restoration plan into account.

REPAIR AND RESTORATION FOR ROAD FACILITIES

Fundamental Strategy

Post-earthquake functions required for road systems may consist of connectivity, reliability, mass transportation and safety. In determining targets of repair and restoration, the post-earthquake demand required for roads should be considered.

Main targets for urgent damage inspection are the following;

1) Capability of passing of cars.
2) Investigation on outline of damages, especially critical damages.
3) Investigation on possible large secondary disasters.

Repair of Highway Bridges

Among various damage patterns, failure of piers, failure of seat concrete and cut-off main members of superstructure are susceptible damages which cause critical failure of bridges. Consequently, damage inspection for temporal repair and restoration shall be first done for these three main items.

The damage degree for temporal repair and restoration shall be judged on the basis of the results of damage inspection as follows:

i) Damage judgement in view of bearing capacity:

A : No Damage	—	No special damages are detected.
B : Slight Damage	—	Damaged, but not influential for short-term service.
C : Medium Damage	—	Influential damage, but possible to use for short-term service unless progress of damage due to aftershocks and live loads is anticipated.
D : Critical Damage	—	Possible falling-off of superstructures is expected due to severe damage.
E : Falling-off	—	Failling-off of superstructures is developed.

ii) Damage judgement in view of passage conditions:

a : No Damage	—	No special damages are detected.
b : Passable With Care	—	Damaged, but passable with care.
c : Unpassable	—	Badly damaged, and unpassable.

Fig. 2 shows one of examples how damage judgement can be made in view of bearing capacity. This example represents check points for judging damage degree of reinforced concrete piers which sustained bending failure at the base.

2) Permanent repair and restoration

The damage degree for permanent repair and restoration shall be judged on the basis of damage investigations as follows:

A : No Damage	—	No damage or minor damage which does not influence functions of bridge with view of long-term service.
B : Slight Damage	—	Damage which does not affect bearing capacity.
C : Medium Damage	—	Damage which affects bearing capacity.
D : Critical Damage	—	Damage which affects significantly bearing capacity.

For selecting permanent repair and restoration method, time required, cost, workability, availability of construction materials and appearance after repairing shall be considered. Table 1 represents permanent repair and restoration methods of reinforced concrete piers which sustained bending failure at the base.

Repair of Road Embankments

With view of serviceability and stability of the road embankments considering the location, depth and magnitude of cracks and settlements of the road surfaces, embankment slope and slope protection works, a classification of the damage pattern and rank is proposed as shown in Fig. 3. As regards to temporary restoration level it is necessary to consider the damage degree, the period until the full restoration is completed and the expected functions of the road during the restoration works.

REPAIR AND RESTORATION FOR RIVER, COASTAL AND SABO FACILITIES

River facilities include river dykes, water revetments, sluice gates, etc. Coastal facilities are coastal dikes, water revetments, detached breakwaters, wave dissipation breakwaters, etc. Sabo facilities are related to erosion control works, landslide prevention works, steep slope collapse prevention works, etc. The fundamentals in the restoration of river, coastal and sabo facilities are to temporarily protect secondary disasters and to execute permanent repair and restoration. Several restoration methods are classified on the basis of restoration purposes considering damage pattern.

Coastal facilities may be damaged by tsunamis, earthquake motions, and high water after the earthquake event. As regards to damages due to tsunamis, damage patterns are classified by examining various damages due to previous tsunamis, and tsunami forces are also clarified.

When an enormous failure of a natural slope occurs, a large amount of soil is piled on a river bed and forms an artificial lake. When such a dammed lake is formed and its break is concerned, urgent measures must be taken. When a break of dammed lake is expected, warning and evacuation must be considered.

REPAIR AND RESTORATION OF SEWER PIPELINES

Sewer facilities are composed of many facilities which include pipelines, machinery, electrical and building facilities. Since pipeline facilities are buried under ground surfaces and have long length, they tend to be influenced by the effects of ground deformations. When they are damaged, it is not easy to find out damaged portions, and to conduct restoration of their function. Therefore, techniques for repairing damaged pipeline facilities of sewer works, are mainly described.

Investigation methods at the second and third stages of repair and restoration are classified into two methods: one is direct investigation method and the other is indirect investigation method. The direct method is to investigate pipeline damage by observation or measurement directly using devices from the inside of pipelines. When the inner diameter of pipeline is too small for investigators to get into, it is effective to utilize a TV camera amounted on a trailing skid or a self-driving crawler, in order to obtain information on pipeline damage.

The indirect method can be used for the investigation of damage of pipelines when it is difficult to get into pipelines. Generally the principle of the indirect method is to find out damage of pipelines

judging from discontinuity of fluid flow. For this purpose, several measurements are proposed.

The purpose of urgent treatment is to prevent secondary disasters by controlling the traffic at the depressed points of road or by pumping out the overflowed water. The temporal repair is implemented to recover the pipeline functions temporarily until the completion of permanent repair. This category of repair includes the removing work of sand which have flowed into the pipelines or manholes. High pressure cleaning mobile and vacuum cleaning mobile can be used to remove sand.

The method for the permanent repairing is selected mainly from the precise investigation results on damage pattern and damage degree. Repairing methods are classified into two groups by considering the purpose of works; one is to prevent leakage and the other is to recover the strength. The characteristics and applicability of each method are provided in the Manual.

CONCLUDING REMARKS

This paper introduces an outline of "Manual for Repair Methods for Civil Engineering Structures Damaged by Earthquakes," which is a result of the Ministry of Construction's project "Development of Repair Methods for Structures Damaged by Earthquakes" performed from 1981 through 1986. Since this Manual is still a draft and is not a mandatory regulation, it can be utilized as a reference guideline when practical engineers conduct repair works for seismically damaged structures such as highway structures, river engineering structures, coastal structures, sabo facilities, and sewer pipelines, etc.

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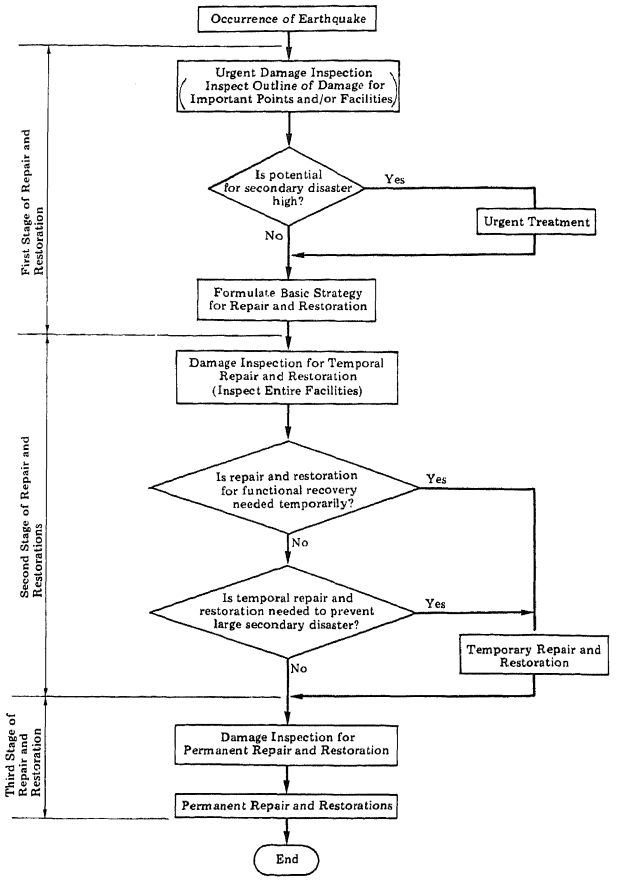


Fig. 1 Flow of Repair and Restoration of Seismically Damaged Facilities

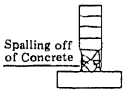
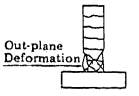
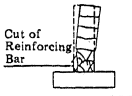
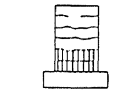
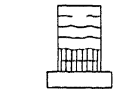
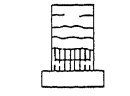
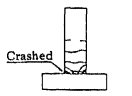
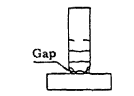
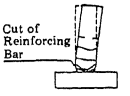
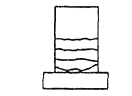
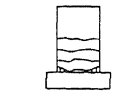
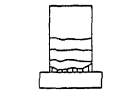
Observed Damage		1 Only Small Cracks	2 Diagonal Cracks (Not Penetrated)	3 Diagonal Cracks (Penetrated)	4 Spalling-off of Cover Concrete	5 Out-Plane Deformation of Reinforcing Bar	6 Cut of Reinforcing Bar and Tilting of Pier
Out-view of Damage	Side View						
	Front View						
	Side View						
	Front View						
Damage-Degree		B: Slight Damage	B: Slight Damage	B: Slight Damage	C: Medium Damage	C: Medium Damage	D: Critical Damage
Residual Strength		$\frac{Pu}{(1.1\,Py \sim 1.3\,Py)}$	$\frac{Pu}{(1.1\,Py \sim 1.3\,Py)}$	1.1 Py	1.0 Py	less than Py	less than Py
Residual Deformability		70%	50%	30%	10%	0%	0%

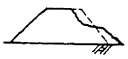
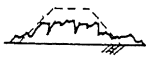
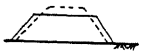
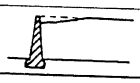
Fig. 2 Damage Degree of Reinforced Concrete Piers which Sustained Bending Failure at the Base

Table 1 Permanent Repair and Restoration of Reinforced Concrete Bridge Pier Which Developed Bending Failure at Its Bottom

Level of Damage		Repair and Restoration Method	Design for Normal Load	Design by Ductility Analysis	
	Damage Patter Presented in Fig. 2			Yield Stage	Ultimate Stage
Before Yield of Reinforcing Bar	Before Stage 1	Injection of Epoxy Regin	Normal	Normal	Normal
		Covering by Reinforced Concrete	Hybrid	Hybrid	Hybrid
		Covering by Steel Plate	Hybrid	Hybrid	Hybrid
After Yield but Before Ultimate	Stage 2 and 3	Injection of Epoxy Regin	2/3 Es for Reinforcing Bar	2/3 Es for Reinforcing Bar	Normal
		Covering by Reinforced Concrete	Ignore Original Section	1/3 Es for Original Reinforcing Bar	Hybrid
		Covering by Steel Plate	Ignore Original Section	1/3 Es for Original Reinforcing Bar	Hybrid
After Ultimate	Stage 4, 5 and 6	Covering by Reinforced Concrete	Ignore Original Section	Ignore Original Section	Hybrid

Note 1) Normal: Usual design procedure in accordance with Design Specifications of Highway Bridge.
2) Hybrid: Original damaged section can be treated to work for load with new section.

Table 2 Classification of Damage Pattern and Damage Rank of Road Embankment on Flat Ground

Damage Pattern	Schematic Figure	Form of Damage
Type I		Slope failure, collapse, cracks and faulting are limited at the embank ment shoulder.
Type II		Sliding failure, crack and faulting reach the central part of embank- ment crown.
Type III		Failure reaches to the subsoils, and the embankment does not show the original shape.
Type IV		Uniform settlement deforms the embankment with keeping the shape to a certain extent.
Type V		Settlement and cracks occur in in fills behind structures.