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Guidelines and Procedures for Post-Earthquake Safety Evaluation and Retrofitting of Harbors and Levees

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ABSTRACT

Parts of the facilities of Taichung harbor and parts of the levees along some rivers in the central-Taiwan area were severely damaged by the 921 Chi-Chi earthquake in 1999. Fortunately, the inundation did not occur then. Evidently, the damages of harbors and levees struck by the earthquake must impact greatly on our transportation and economy. Since being one of the most threatened catastrophes in Taiwan, it is urgent to set up related measures to reduce the influence of adversities.

This project is to consult the related domestic and foreign reference and restoration (including chiefly the Kobe earthquake and the 921 Chi-Chi earthquake), and to analyze the possible destruct model and the cause of harbors and levees damaged by an earthquake. Thus, this report provides corresponding measures as well as the quick diagnosis handbook (including standard of operation, checking and diagnosis tables) and the quick retrofitting/strengthening method (including retrofitting techniques and procedures of operation), for the authorities concerned in proposing for the hazard mitigation and reconstruction.

Keywords: harbor, levee, earthquake, quick diagnosis,
quick retrofitting/strengthening

OBJECTIVE

Taiwan lies on the subduction zone between the Eurasia Plate and the Philippine Sea Plate. And such, there is a high level of seismic activities which inevitable leads to the fact that earthquakes is one of the most important natural catastrophe in the republic. The 921 Chi-Chi earthquake in 1999 caused uneven settlement, liquefaction, damages to transportation facilities,

damages to foundations and storage tanks and cracking in buildings and roads of Taichung harbor (located in central-Taiwan). This has seriously affected the normal operations of the harbor. Also, the 921 Chi-Chi earthquake has damaged a majority of levees in central-Taiwan, especially MaoLuo Stream where 14,000 meters of levees was damaged. Fortunately, inundation did not occur, sparing Taiwan of another disaster. Since harbors and levees are important facilities which ensure the smooth and safe transport of goods and service, they impact greatly on the economy should they be brought out of service. There is therefore this need for immediate assessment, repairs, restoration and retrofitting/strengthening of harbors and levees when the next massive earthquake strikes. In order to be able to achieve this in an efficient manner, operation standards and procedures, post-earthquake handbooks and manuals, need to be produced for relevant authorities. This will ensure that within the shortest time frame possible, all assessments, repairs and restoration works be completed; so as to minimize not only the damages to harbors and levees, but also to the greater extent, the impact on our economy and the society as a whole. Although most of structures in central-Taiwan have been fully restored, relevant authorities still feel that there is a lack of experience in dealing with this type of crisis. Hence, there is much anticipation and hope on this project.

DISCUSSIONS AND CONCLUSIONS

This research includes detailed investigations into the quick diagnosis and retrofitting/strengthening methods, collection and analysis of practical examples (with reference from the 1995 Kobe earthquake and 1999 Chi-Chi earthquake), administrative procedures of local authorities, and technical information on harbors and levees. The following are conclusions obtained:

Preventive Measures before and Immediate Actions to Undertake after an Earthquake of Harbors and Levees

Basic Requirements

Any moderate or strong earthquakes cause severe damages to harbors and levees, which in turn have a major impact to the lives of people and the economy. This report looks into the government's disaster prevention and assistance law and earthquake distribution scale.

1. Preventive measures before an earthquake includes: Prediction, announcement and prevention prior to any earthquake; establishment of professional bodies; establishment of back-up communication lines; weather forecasts; procedure for restoration works after an earthquake; inspection during construction to ensure preventive measures and escape routes; compilation of consultancy firms and contractors specializing in strengthening/ retrofitting and repair works; and drafting up of emergency bidding systems.
2. Immediate action during an earthquake includes: Systematic distribution and use of manpower, water and electricity, and facilities; set up communication network so as to reduce and control the spread of victims' distress and or disasters;

allocation of personnel and ships for evacuation purposes; and coordination of external aid.

3. After the earthquake, immediate assessment and repair works shall commence, starting from harbors and levees to surrounding facilities (electricity, telecommunications, roads and rail); with greatest emphasis placed on water disasters, secondary emphasis on transportation.

Administrative Units

There should be a set up of a special unit during peace times to deal with natural disasters, a unit for coordination and communication to coordinate and distribute work amongst the different rescue teams in an efficient and responsive manner to complete all preventive or rescue works.

Assistance and Coordination between Relevant Authorities of Harbors and Rivers

1. When a natural disaster strike a harbor, it should immediately inform all ships to sail to other harbors while also assisting all other damaged ships to safe areas; correspondingly, other harbors are obliged to send towboats to tow all damaged ships.
2. Any harbor hit severely by natural disasters, all neighboring harbors are to send technical assistance who may be equipped with the necessary equipments to aid.
3. The restoration works of severely damaged structures may be passed in whole to other units.
4. For the case of serious catastrophes like water disasters, the government has the authority to order military, police or the engineering industry to assist in repair and rescue works.

Routine Inspection of Harbors and Levees and the Set up of Information Database

Important facilities such as harbors and levees shall be routinely inspected from time to time and information obtained complied into a database; with all previous repairs and damages recorded. The availability of this crucial information will reduce the time needed for future repair works.

Monitoring System and Suggestions

As the western coast of Taiwan is mainly a delta and due to the effects of the lowering down of ground water table and liquefaction during strong quakes, structures are subjected to tilting and excessive settlement. Therefore, there is a need for a monitoring system in place to make restoration works easier. The monitoring system shall monitor changes in the ground water table pressure, surface and ground earthquake waves' speed and magnitude, and the amount of settlement.

Immediate Inspection and Measures of Harbors and Levees after an Earthquake

The Importance of Immediate Inspection

Immediate inspection of harbors and levees after an earthquake ensures obtaining a clear picture of the extent of damage sustained, and the possibility of another disaster striking; and to commence repairs and strengthening/retrofitting works so as to contain the catastrophe.

Checklist

Immediate inspection requires that it be complete within as short a time frame as possible, therefore the need for a short and precise checklist. Items to check includes: transportation system, drainage system, roads, slopes, all other

facilities, pier location, settlement as a whole, concrete cracks, exposed reinforcements, foundations, liquefaction, displacements of levees, other public utilities including power supply, lighting, telecommunications, and sewerage system.

Standard and Method for Immediate Inspection

Immediate inspection should be carried out on patrol cars whenever possible. If in the event those patrol cars are unable to access the disaster areas, inspectors shall proceed on foot. Equipment to be brought along includes: lighting equipment (for example hand torch); record sheet; camera or video camera; measuring tape; bamboo stick; radio communication devices; traffic control and warning signs etc. The majority of the inspectors shall be picked from harbor or levee units and there shall be as many teams doing immediate inspection concurrently as possible. Each team shall be made up of 2 ~ 4 persons and shall be decided based on local conditions.

This report shall categorize the extent of damage into 3 categories, namely A, B and C. Category A implies minor damage, not affecting traffic. Category B refers to situations where bridges or tunnels show signs of displacements, cracking, location shifts, flooding, etc, and where traffic is affected. Lastly, Category C refers to the situations where the slopes by the side of roads fails, settlement or swelling of the road surface, obstruction or where traffic is impossible.

Actions to Undertake

If there are signs of an impending second disaster, undertake the following actions. The first stage depends on the category of damage sub stained. For Category B where damage is moderate, traffic control shall be carried out, warning signs shall be set up to mark out dangerous areas, announcements shall be made over media and efforts to improve the situation shall commence as soon as the above steps are completed. For Category C, stop all traffic across the affected area until repairs have been completed.

Quick Diagnosis of Harbors and Levees after an Earthquake

The Importance of Having a Quick Diagnosis

After completing the immediate actions after the quake, there is a need to assess the current conditions of harbors and levees, so as to be able to understand primarily their safety levels and secondarily, their functionality levels. Next, decision on whether further strengthening/retrofitting works are needed or further safety tests required is made.

Items to Check and Method

The objective of this check is mainly to assess the degree of damages, whether the damages are contained or expanding of harbors and levees. Simple equipment made is used to take down information of this nature, which may be needed for reference in future repairs. The items to check for and the method to be employed are identical to those of immediate inspection checklist.

Standard of Assessment

1. Quick safety assessment and safety levels

For the purpose of this report, safety levels are categorized into Level I, II and III, respectively. When an area poses danger to the user, it is categorized as Level III. Other than imposing traffic control, there is also a need to

immediately conduct safety checks and proper repair works. When an area does not pose immediate danger to the user, it is classified as Level II and after quick strengthening/retrofitting; it can be opened for limited use. However, safety checks are required be scheduled to be conducted in such areas. When the area has only sustained minor damages, it is classified as Level I and do not require any safety checks.

2. Standard for quick safety assessment

The criteria for quick safety assessment will depend on the location and type of situation. When all check items are classified as either Level II or III, the safety level of the most important facility of the whole area is used as the Quick Safety Assessment level of that particular area.

Points to note when conducting Quick Safety Assessment: ①safety levels are subjective due to its descriptive nature, therefore the need to place great emphasis on observation and past experience; ②if the situation seems to be expanding into other areas, it is required to be noted down; ③when it is obvious that the safety level of an area is of Level III, obtain confirmation from inspectors and implement strengthening/retrofitting works with safety checks conducted as soon as possible; ④ quick safety assessment primarily assess a whole facility as one and when needed, a certain area may be assessed separately; ⑤the final safety level of an area is the most severe safety level obtained.

Procedures to Strengthen/Retrofit Harbors and Levees after an Earthquake

Importance of Performing Strengthening/ Retrofitting Works Promptly

Strengthening/retrofitting works plays an important role especially when repairs are hard to carry out and rebuilding is not an option. It reduces the possibility of an occurrence of a second disaster, cut down losses, reduce time for restoration and cuts down the use of resources. From experience obtained from the Kobe earthquake and 921 Chi-Chi earthquake, most harbor and levees facilities are usually strengthened/retrofitted when they are damaged.

When to Strengthen/Retrofit and Method Employed

1. When damage to harbors and levees are of category C, tilting or displacements, settling, etc, where its intended function is affected, strengthening can be used.
2. For gravity caisson wharf, it can be repaired using the Re-alignment method, Gravity caisson separation method, or Pile separation method. For pile wharf, it can be repaired using Pile separation method. And for the case of levees, its height can be extended, or river channel deepened, or both methods employed at the same time.

Engineering Aspects of Strengthening/ Retrofitting Method

As the structures of harbors and levees depends to a large extent local conditions, and difference in earthquake magnitudes and degree of damage, there is no standardized methods of repairs. Using experience derived from Kobe earthquake and 921 Chi-Chi earthquake, guidelines are obtained:

1. The main construction methods for harbors in Taiwan include Gravity Box Method, Sheet Pile Method, Gravity Caisson Method and Pile

Method. The former two if damaged is technically difficult to retrofit/strengthen or even repair.

2. Regarding Gravity Caisson wharf and Pile wharf, from experience, the Gravity Caisson wharf appears to be more vulnerable to damages. Parts of the wharf usually becomes misaligned and to correct this, the following methods may be employed: Realignment of gravity caissons and if earth pressure subsequently becomes too large, excavations may be carried out and soil improvement performed; Gravity Caisson Separation method involves construction of a new wharf when the existing one is damaged beyond repairs, having the disadvantage of a loss of docking space; Pile wharf method is similar to the gravity caisson separation method in that a new wharf is constructed by piling; or lastly, the H-beam pile method to align the existing wharf by filling in the voids between caissons.
3. For levees on the west coast, when damaged, a new layer of concrete may be cast on to the existing structure. A new protection layer may be added to the water face or the creation of a gentler slope may also be possible through the addition of a new concrete layer. For levees on the east coast, retrofitting/strengthening works will depend on local ground conditions and breakwaters need to be strengthened/retrofitted. Also, the levee may be thickened or added with an impermeable layer.
4. Usually after an earthquake, landslides of slopes next to a river will rise the channel bed and cause a blockage to the free flow of water. Immediate steps to dig a channel to allow the flow of water to continue are of utmost importance. When the danger of a flood has been removed, further clearing works should continue. In the case of laking, the whole clearance works may be passed on to another unit as an individual case.
5. Improvements to local ground conditions: Stone Column Method and Compressed Stone Method involve the addition of stones into the ground under compression so as to achieve ground improvement. Vibration Method makes use of mechanical strength to lift a weight and hitting the ground. Dissipation Method involves the addition of crushed stones into the ground so as to reduce the possibility of liquefaction. Grouting Method involves the addition of chemicals to the ground in an attempt to alter in-situ soil conditions.

Administrative Procedures for Strengthening/Retrofitting Works

As there has been no standardized procedure available, a flowchart with respect to quick assessment, strengthening/retrofitting work, etc., has been provided.

Hand Manual for Strengthening/Retrofitting Works of Harbors and Levees after an Earthquake

The previous areas mentioned (such as quick assessment, and strengthening methods) have been compiled in a hand manual “Guidelines and Procedures for Post-Earthquake Safety Evaluation and Retrofitting of Harbors and Levees” for future references.

After the occurrence of a disaster, the relevant authorities (for example, harbor bureau) should immediately form a team under the supervision of the commander or vice-commander to maintain open

communication lines with the outside world (including superior, relevant authorities and media); when necessary request for aid from other units; and to coordinate the whole operation. A committee should also be set up, consisting of specialists, professionals, and relevant government personnel, to provide technical assistance and supervision, post-earthquake surveys and safety checks and repairs.

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REFERENCE

1. Ministry of Transportation and Communications (1990). *Seminar Proceedings for Earthquake Resistance of Traffic Engineering*, December.
2. Lai, K.C. (1999). "Study of resistance of public buildings to natural disasters," Public Construction Commission, June.
3. Hsu, M.H., *et al.* (1999). "921 Chi-Chi Earthquake damage report — water facilities damage report," National Center for Research on Earthquake Engineering, November.
4. Lo, C.H., *et al.* (1999). "Central Taiwan Chi-Chi Earthquake of 21st September 1999 preliminary damage report (2)," National Center for Research on Earthquake Engineering, November.
5. Water Conservancy Agency Ministry of Economic Affairs (1999). "921 earthquake report — water facilities damages and restoration works (version 1)," November.
6. Huang, C.T. (1999). "Management of 921 Earthquake damages and restorations to Taichung Harbor," *Post 921 Earthquake Retrofitting and Strengthening of Traffic Falicities Seminar*, December.
7. Institute of Harbor and Marine Technology (1999). "Research on settlement in harbor areas — study of data collection system of settlement in An-Ping Harbor," December.
8. Su, C.L. (2000). "Analysis of Piers 1~4A of Taichung Harbor after 921 Earthquake," Harbor Report, No. 51, January.
9. Yu Tai Consulting Engineering Company (2000). "Initial findings of causes of damages to north wharf of Taichung Harbor after 921 earthquake," April.
10. China Engineering Consultants, Inc. (2000). "921 Chi-Chi Earthquake (revised edition)," April.
11. Institute of Harbor and Marine Technology (2000). *Proceedings of Harbor Earthquake Resistance and Prevention Seminar*, July.
12. The Japanese Geotechnical Society and Japan Society of Civil Engineers (1997). "Report on the Hanshin-Awaji Earthquake disaster (damage to civil engineering structures)," December.
13. The Japanese Geotechnical Society and Japan Society of Civil Engineers (1997). "Report on the Hanshin-Awaji Earthquake disaster (emergency repair and seismic retrofit)," December.

14. The Japanese Geotechnical Society, (1997). "Report on the Hanshin-Awaji Earthquake disaster (investigation of causes of damage to civil engineering strutures, port and coast facilities)," December.
15. Port and Harbor Research Institute (1997). *Handbook on Liquefaction Remediation of Reclaimed Land*, Ministry of Transport, Japan.
16. National Center for Research on Earthquake Engineering (2000). *Proceedings of International Workshop on Annual Commemoration of Chi-Chi Earthquake*, Vol. I ~ IV, Taiwan.