Manual for Forecasting Earthquake and Tsunami Damage to Public Civil Engineering Facilities (proposal)

by

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ABSTRACT

In order to reduce damage from earthquake and tsunami, while it is effective to forecast damage and to formulate and implement countermeasures based on such estimations, a method of forecasting earthquake and tsunami damage to public civil engineering facilities has not been established. This is a report on our proposal for a method of forecasting damage to port facilities and a policy manual for applying the damage forecast results.

KEYWORDS: Damage forecasting, Earthquake , Port facilities, Tsunami

1. INTRODUCTION

It is feared a large-scale earthquake accompanied by tsunami will occur within the next 30 years, such as a Tokai earthquake, a Tonankai earthquake, and Nankai earthquake. For this reason, the Central Disaster Prevention Council and local governments are forecasting damage from large-scale earthquakes which are presumed will occur in the future. While these damage forecasts estimate building damage and human damage caused by earthquakes and tsunami, a policy for the comprehensive planning of earthquake and tsunami countermeasures which assumes damage to public civil engineering facilities does not currently exist as a reference to prevent such damage and handle emergency goods transport. This manual presents methods for forecasting earthquake and tsunami damage and application guidelines as a reference. The details of these methods should conform with these guidelines, among other standards.

2. FORECASTING DAMAGE TO PORT FACILITIES

2.1 Forecasting damage

Forecasting damage by earthquake and tsunami requires data on the various external forces of phenomena (maximum acceleration, flood depth, etc.). In many cases, the earthquake motion and tsunami simulation results conducted by the Central Disaster Prevention Council and local governments are stored as numerical data, and it is possible to determine these external forces from this numerical data. In recent years, it is becoming relatively easier to conduct tsunami numerical simulations and detailed collection of elevation data for low-lying seaside areas is being conducted. Therefore, if the results of previously implemented simulations for use as reference cannot be obtained, implementing new tsunami simulations and determining external forces can be considered.

As well, other data required for damage forecasting will include strength of seismic movement, tsunami height, and facilities structure, among others. Provision of this data can be requested from the body implementing earthquake and tsunami damage forecasting, or a new estimation of strength of seismic movement and tsunami height can be performed.

2.2 Damage to facilities from earthquake motion

Damage to port facilities from earthquake motion will be forecasted based on the Technical standards and description of port facilities" revised in 2007[1]. Until now, earthquake-resistant design of port facilities has involved the application of a seismic coefficient method which replaces the dynamic action of earthquake motion with static inertia force. In dynamic analysis, earthquake response analysis employed seismic waveforms measured at points different from the points targeted for des-

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ign such as by Hachinohe and Kobe. However, earthquake motion was dependent on the source properties, propagation path properties, and ground characteristics of target points, and earthquake response of facilities was dependent not only on the vibrational amplitude of input earthquake motion, but on the frequency characteristics of earthquake motion, ground, and structures. For this reason, when checking the aseismic capacity of port facilities, a method of calculating the action of earthquake motion is employed which considers the properties of subsurface ground and structures, based on the time history wave form of earthquake motion in the engineering bedrock derived by considering source properties, propagation path properties, and ground characteristics (site characteristics).

The following points are described for port standards.

1. With respect to level 1 earthquake motion (earthquake motions with the probability of occurring once or twice during the operation of facilities), the stochastic time history wave form should be appropriately determined based on measured values of earthquake motion, and considering source properties, propagation path properties, and site properties.
2. With respect to level 2 earthquake motion (earthquake motions possessing the maximum intensity imaginable at the targeted points from the present to the future), the time history wave form should be appropriately determined based on measured values of earthquake motion and assumed earthquake source parameters etc., and considering source properties, propagation path properties, and site properties.

Figure 1 shows methods of forecasting damage to port facilities from earthquake motion.

- Static analysis methods
  - Seismic coefficient method
  - Modified seismic coefficient method
  - Response displacement
  - Ultimate earthquake resistance method
- Dynamic analysis method
  - Response spectrum method
  - Time history response analysis
    - Time history modal analysis
    - Direct integration method
    - Frequency response analysis

Fig.1 Methods of forecasting damage to port facilities from earthquake motion

As well, Table 1 shows the results of considering the adaptive flexible of methods of forecasting earthquake damage to various port facilities.

2.3 Damage to breakwaters by earthquake motion and tsunami

The cross-section of breakwaters is generally determined according to the external force of ocean waves, a consideration of level 1 earthquake motion is often omitted. However, in cases where the installation water depth is deep and design wave height is small, consideration of external force due to level 1 earthquake motion becomes predominant. For this reason the necessity of checking aseismicity is judged from the relationship between cross-sectional data determined by the external force of ocean waves and level 1 earthquake motion. The checking of aseismicity is conducted if it is judged necessary according to port standards shown in the “necessity judgment diagram of aseismicity checking.” When checking sliding and toppling capacity is deemed necessary, such methods will be conducted in accordance with port standards.

Damage to breakwaters from tsunami consists of deformation due to tsunami wave force,

Table 1 Adaptive flexibility port facility earthquake damage forecasting methods

Damage forecasting methods	Target facilities	Structural format
Simple forecasting method	Pier, embankment	Gravity structure earth fill
Seismic coefficient method	Pier, embankment, flood gate, land lock, drainage pump station, shed, warehouse	Gravity structure, sheet-pile type structure, earth fill
Ultimate earthquake resistance method	Pier, road bridge	Vertical pile pier
Response displacement method	Tunnel lifeline	Shield tunnel Water supply, sewage line, common ducts, etc.
Response spectrum method	Railroad facility	
Dynamic response analysis (total stress)	Tunnels All structures	Submerged tube Almost all structural formats
Dynamic response analysis (effective stress)	All structures	Almost all structural formats (when liquefaction is considered)

deformation due to ocean flow, and deformation due to a combination of wave force and ocean flow, and is similar to deformation chain architecture by ocean waves. In particular, problematic damage from tsunami can be evaluated according to items 1)–3) below.

1) Stability of breakwaters in the event of tsunami

Tsunami wave force and uplift pressure are considered the external forces when investigating breakwater dislocation due to sliding, breakwater dislocation due to toppling, and breakwater dislocation due to lack of mound bearing capacity. The tsunami wave pressure formula proposed by Tanimoto et al. is used for this investigation.[2]

2) Scattering of the breakwater covering rock

To investigate the scattering of breakwater covering rock on the port side (leeward side) and on the ocean-facing side, the relationship between current drift in the mound vicinity and the weight stability limit of the covering rock etc. is considered utilizing the Isbash formula[1] to derive the stable mass of covering materials in relation to current velocity. Scattering is judged will occur in the event that the weight of the covering rock used is less than stable mass.

3) Movement and scattering of breakwater wave breaking works

An evaluation formula regarding the scattering of wave breaking works due to tsunami does not exist. Thus, scattering experiment results relating to deformed block levees due to tsunami soliton fission[3] will be useful as reference. The results of these experiments show that the destructive force of tsunami is dramatically greater than normal ocean waves.

2.4 Embankment deformation due to earthquake motion and tsunami

To quantitatively check the volume of structural deformation such as slanting of the embankment, it is necessary to employ Time History Response Analysis methods as indicated in Figure 1. Time History Response Analysis methods can be divided into the total stress analysis method and the effective stress analysis method. Typical analysis programs for the total stress analysis method include “SHAKE” and “FLUSH,” and typical analysis programs for the effective stress analysis method include “FLIP” and “LIQCA.” It is necessary that they be chosen according to the amount of excess hydrostatic pressure which occurs.

As shown in Figure 2, tsunami damage to embankments can be categorized into 3 types: damage due to wave force; damage from scouring of the frontal side; and damage from scouring of the leeward side. In estimating

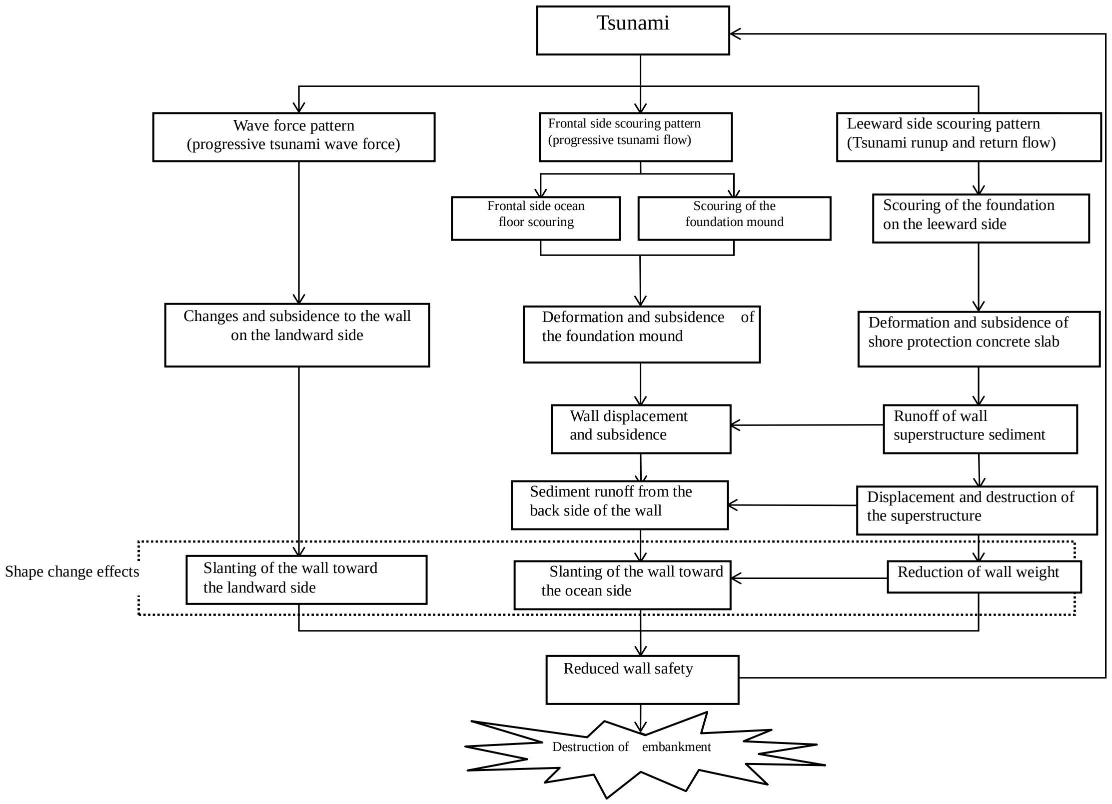

Fig.2 Major chain of damages to gravity revetment due to tsunami

damage, it is necessary to accurately forecast embankment displacement and subsidence until sloping occurs, and shape changes from the scouring of the ground foundation etc. through appropriate methods. Specifically, regarding damage from scouring to the leeward side (due to return flow of tsunami run-up), the results of considering ground scouring of the leeward side of the embankment, and caisson wall and superstructure stability despite the load of return flow drag applied, will serve as reference. [4]

2.5 Assessment of driftage

Main driftage which is observed when a tsunami hits a port region includes maritime containers, wood materials, and boats etc. The driftage area is forecast using driftage simulation methods which can accurately replicate driftage behavior. The behavior of driftage can be calculated by solving the motion equation of driftage. This is accomplished by applying the results of flat surface two-dimensional tsunami analysis as the external force of driftage such as maritime containers, wooden materials, and boats etc.

In addition, by judging the contact between driftage and structures as well as considering colliding force, the drift and collision behavior of driftage can be more accurately considered, including the collision phenomenon. Figure 3 is a flowchart of driftage behavior forecasting due to tsunami.

By calculating the drift and collision behavior of driftage, this data can be applied to check the safety of structures such as berth facilities and shore protection structures from driftage collision, understand how risk of spillage can be reduced by adequately developing and consolidating storage locations for maritime containers etc., and understand the effect of developing facilities to prevent spillage etc. Regarding methods of calculating collision force by driftage, various previous research can be referenced such as the study by Matsutomi et al. targeting driftwood, and the study by Mizutani et al. on maritime containers. As for methods of calculating drift and collision behavior of driftage due to tsunami, there are also studies which combine the flat surface two-dimensional

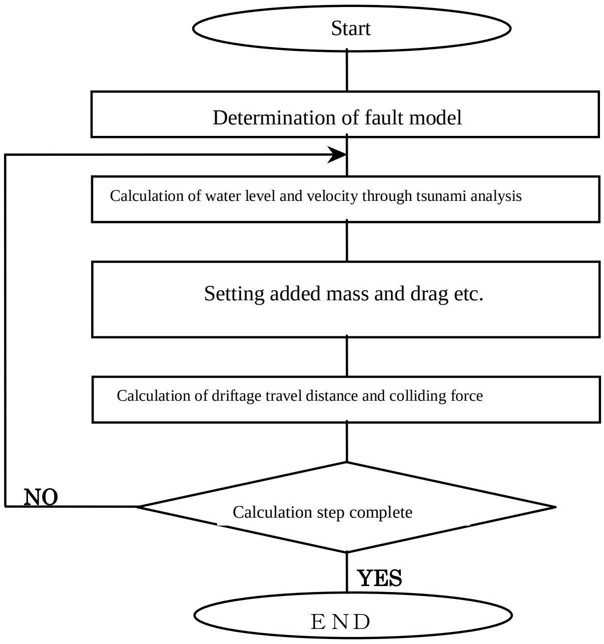

Fig.3 Flowchart of driftage behavior forecasting due to tsunami

tsunami numerical simulation with a shape representation and collision analysis of driftage employing a distinct element method. When checking the safety etc. of structures, it is desirable that an appropriate calculation method be adopted based on the results of conducting trial calculations using these various calculation methods. [5][6][7][8]

3. Policy course for applying damage forecast results

3.1 Creation of a damage forecast map

By creating a damage forecast map showing the results of forecasting damage to public civil engineering facilities and flooded areas due to earthquake and tsunami, and upon considering geographical conditions etc. according to area, it will be possible to consider specific earthquake and tsunami countermeasures in collaboration with related agencies. As well, by indicating the locations of important bases in the event of disasters and public agencies on the map, it will be possible not only to consider hard infrastructural countermeasures (development and reinforcement of public civil engineering facilities), but to consider measures for mitigating damage by applying soft infrastructural measures (information provision and improvement of initial response system).

As an example, Figure 4 shows a damage forecast map focused around Susaki Port in Kochi prefecture. In addition to the results of assessing damage to various facilities and flooded areas etc., the map indicates tsunami arrival time, flooded regions, the position of government facilities and hospitals, damage to humans and buildings evaluated based on bridge reinforcement methods etc., which will be useful as reference in formulating earthquake and tsunami countermeasures. As for tsunami protection facilities such as tidal barrier, creating maps of damage to flooded areas and hinterland areas before and after implementing reinforcement and new facilities construction countermeasures will serve as reference for judging the necessity of implementing such countermeasures.

By creating such maps, it will be possible to consider specific measures relating to the implementation of emergency drills, the provisioning of information, evacuation routes, evacuation space, preliminary plans to carry out

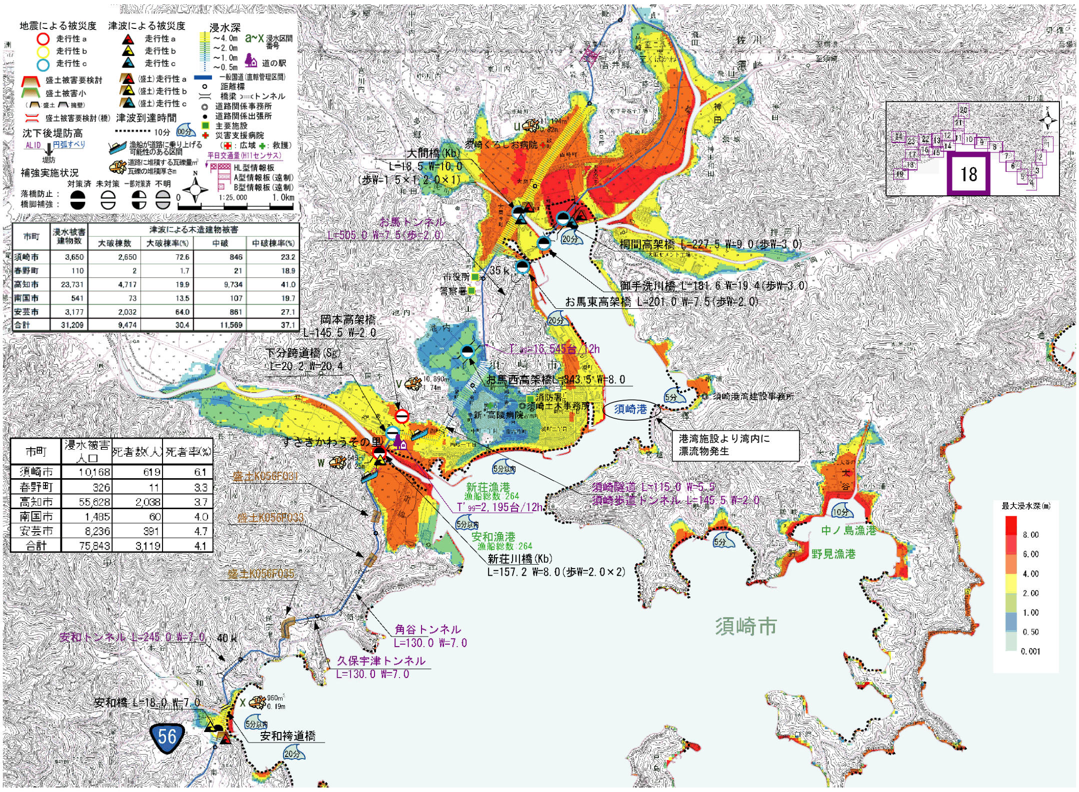

Fig.4 Damage forecast map (Susaki Port)

efficient emergency and recovery activities, tsunami protection facilities which are particularly effective to mitigate damage, and facilities which should be prioritized for reinforcement.

However, damage forecasting is at most a starting point for considering specific measures, and there will also be situations where actual damage will not occur according to forecasts. Therefore, in formulating countermeasures, it is necessary that planning be conducted flexibly considering that unforeseen events may also occur.

3.2 Sharing and application of damage forecast results

In planning earthquake and tsunami countermeasures, it is also important that the results of damage forecasts to public civil engineering facilities etc. be shared with related agencies. As forecasted damage to coastal and riverside facilities and countermeasures by public civil engineering facilities will influence forecasts on flooded areas, this will lead to functional impairment of port facilities. As well, it will also be necessary to consider the effect of driftage from port facilities when planning countermeasures. Therefore, by having related agencies exchange information relating to damage forecasts and earthquake and tsunami countermeasures etc., it will be possible to formulate a highly effective and comprehensive plan for countermeasures. Specifically, it is desirable that related agencies discuss countermeasures including their respective apportionment of responsibilities at disaster prevention conventions etc.

As well, consensus-building with citizen involvement is now underway from the planning stages of disaster prevention activities. By appropriately conducting damage forecasts utilizing this manual, as well as for the sake of confirming the effectiveness and thinking behind the planning of countermeasures, not only can the smooth implementation of activities be anticipated, but it is surmised this will contribute to raising the government’s responsibility to explain its policy measures to the public etc.

While there may be cases where port plans etc.

may be changed depending on the disaster activities included within countermeasure plans, it is surmised that damage forecast results will also be effective as basic materials for explaining the necessity of the positioning of such activities within the plan. As the level of damage as a result of developing facilities or not developing facilities can be estimated by applying the damage forecasting method indicated in this manual, it can also be applied when evaluating public works.

4. CONCLUSIONS

This manual has organized and systematized various research results relating to earthquakes and tsunamis. While research relating to earthquakes has made great headway, much progress in research relating to tsunamis can be anticipated from future research by relevant parties.

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