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STRATEGY FOR SEISMIC UPGRADING OF CHEMICAL PLANT TAKING PRODUCTIVITY AS CRITERION OF JUDGEMENT

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ABSTRACT

Seismic upgrading and modification of existing chemical plant facilities have been performed by means of a procedure of the Seismic Design Code and Guidelines of High-pressure Gas Facilities in Japan. Main purpose of this seismic design code is to ensure public safety at seismic events. From the viewpoints of seismic risk of corporate management, CSR (Corporate Social Responsibility) and productivity of the plants are also important for seismic assessment. In this paper, authors proposed strategy for seismic assessment to select appropriate pre-earthquake upgrading and modification considering productivity of plants based on fault tree analysis. This assessment will enable to select weak damage modes and to allocate countermeasure cost optimally to the selected damage modes.

Keywords: Seismic risk assessment, Chemical plant facilities, Damage level, Fault tree, Productivity of plants

1. INTRODUCTION

At present, seismic design of chemical plant facilities mainly complies with “the Seismic Design Code of High Pressure Gas Facilities in Japan (Revision of notice No.143, Ministry of International Trade and Industry)”. This notice establishes required seismic performance against two levels' earthquakes, that are Level 1 earthquake (operating basis earthquake, the probable strong earthquake in service life of the facilities), and Level 2 earthquake (safety shutdown earthquake, the possible strongest earthquake with extremely low probability of the occurrence), to achieve the target of minimizing environmental damage caused by damage and loss of function of equipment. In this notice the main purpose of seismic design is to ensure public safety at seismic events.

From the viewpoint of CSR (Corporate Social Responsibility), though the most important goal is to be secured the public safety, continuance of corporate activities should also be required to secure production supplies, and to maintain equipment and prevent damages at seismic events. In future the authors presume that seismic design should be executed to achieve not only ensuring the public safety but also ensuring the productivity.

There are two types of measures to ensure the productivity, “risk control” to prevent earthquake damage and “risk finance” to compensate the operating capital after seismic events. Although these measures are basically applied with effective combination, it is important to adopt “risk control” first to mitigate the load due to “risk finance”. Concrete measures of risk control may include increasing the level of design ground motions for new structures and seismic upgrading for existing structures.

Meanwhile ensuring of public safety is stipulated by the seismic design code (revision of notice No.143), but there is no apparent performance specification for ensuring the productivity. On the condition that public safety is ensured, it is necessary to conduct performance specification for ensuring the productivity on the basis of judgment made by corporate managers.

Concerning existing chemical plant facilities, the relationship between seismic countermeasures and improvement in seismic performance cannot be clearly identified because of the complexity of their functions. And it is necessary to correlate the investment amount for seismic upgrading to the corresponding improvement in seismic performance, then optimum seismic countermeasures should be proposed by using the relationship. The “optimum seismic countermeasures” defined here, means the measures deemed to have a maximum cost-effectiveness, and this is important from the standpoint of the accountability to their shareholders.

In this paper an approach to develop optimum seismic countermeasures is studied and proposed in order to realize the best effective investment for seismic upgrading of existing chemical plant facilities with an emphasis on ensuring the productivity. Furthermore this approach is effectively applicable for existing nuclear power plants and their related facilities instead of chemical plant facilities.

2. OUTLINES OF ASSESSMENT METHOD

Proposed approach of seismic assessment in this study will be able to specify components to be upgraded and their degrees of upgrading, by assuming the investment amount for seismic upgrading of equipment and levels of productivity retained after earthquake, of which level is defined by the period of suspension of the operation and the necessity of repair work.

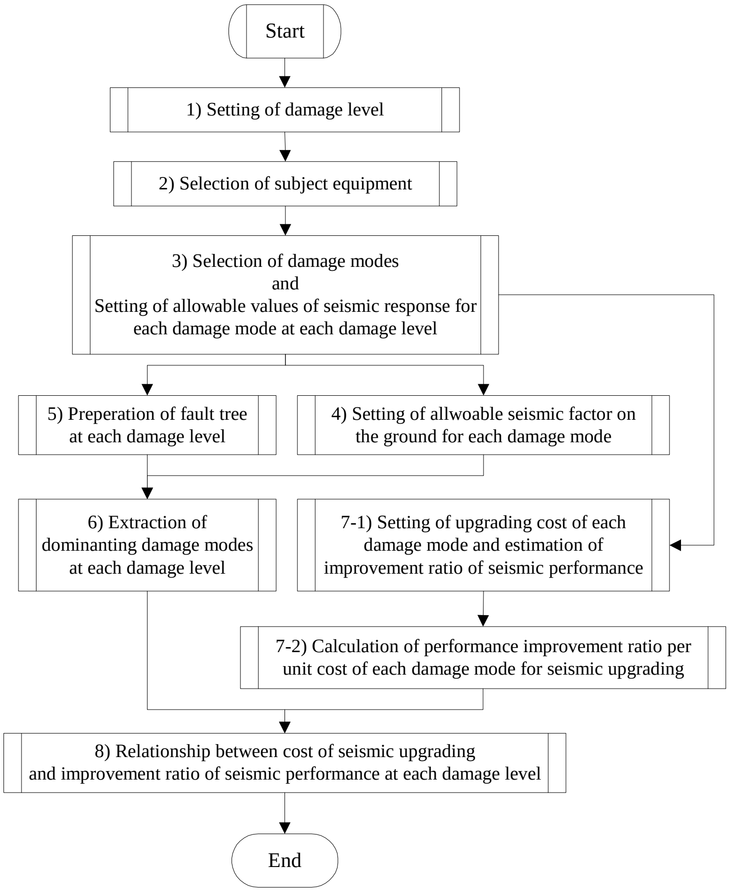

Fig-1 Flow chart of assessment procedure

This approach consists of the following steps. First damages caused by seismic events are classified into groups called as damage levels from the standpoint of productivity. Secondly, fault trees of each damage level are developed by using an event which takes place on the components of equipment and causes damages to the performance of the equipment, (called as damage modes, hereinafter), as a basic event. Thirdly, investment amount of the seismic countermeasures based on the entire fault tree is calculated based on results of cost estimates for seismic upgrading corresponding to each damage mode.

Finally for each damage level, a relationship between the investment amount for seismic upgrading and seismic factor on the ground, and a relationship between the investment amount and the improvement ratio of seismic performance are identified, and these relationships are applied to the assessment for seismic upgrading.

The flow chart of assessment procedure is shown in figure-1, and explanation of the flow chart is itemized as follows.

1) Setting of damage levels: Subject equipment is considered to be total plant system or parts of the system, and their damage levels are defined based on estimated operating condition and necessity of repair, which are judged from the degree of plastic deformation and damage. These damage levels apply to evaluate damage of total plant system from the standpoint of productivity.

2) Selection of subject equipment: The equipment dominating plant operation in decision of damage levels considering productivity of total plant system may be selected as subject equipment. The extents of the subject equipment may vary from equipment, or one unit consisting of equipment of single process, to all the plant system consisting of several units. Here, the extents of subject equipment are selected.

3) Selection of damage modes: Damage modes of the subject equipment are selected from recorded cases and literature concerning damage caused by past seismic events. For the each selected damage mode, threshold values will be set based on allowable values of seismic responses.

4) Setting of allowable seismic factor on the ground for each damage mode: The values of seismic factors at which responses correspond with the threshold values, are calculated using seismic response analysis of the subject equipment. Seismic factors on the ground are used as an indicator of strength of components or equipment against seismic ground motion. These “seismic factors on the ground” mean the ratio of calculated acceleration on the ground divided by the acceleration of gravity.

5) Preparation of fault trees at each damage level: The fault trees, which provide means to combine qualitative analysis such as a causal relationship or (and) development process and quantitative analysis using probabilistic calculation, are used to select damage modes of the structure consisting of many members and components, such as the plant facilities. In this assessment method, fault trees are prepared using AND gate and OR gate in order to correlate damage modes of fundamental events to damage events of each facility.

This fault tree is prepared for each subject facility and for each damage event of the facility.

6) Extraction of dominating damage modes at each damage level: In order to specify the damage modes determining the damage events of the subject equipment, the damage modes dominating the damage events of the facility (called as “dominating damage mode”, hereinafter) are extracted using fault trees at each damage level.

7) Setting of seismic upgrading cost for damage modes and improvement ratio of seismic performance: After setting of the most cost effective countermeasure of seismic upgrading for each damage mode, the proportion of the seismic performance improved by the seismic upgrading to the original seismic performance is defined as the improvement ratio of seismic performance. Next in case of seismic upgrading for total facilities, the improvement ratio for total facilities is defined as proportion of the minimum seismic factor on the ground among the allowable seismic factor on the ground of the “dominating damage mode” at each damage level, to ones calculated as the target of seismic upgrading at proposed damage levels. Then as the improvement ratio of seismic performance for each damage mode, the improvement ratio per unit cost of seismic performance is calculated by cost of seismic upgrading and improvement ratio of seismic performance after seismic upgrading.

8) Relationship between cost of seismic upgrading and improvement ratio of seismic performance: At each damage level, the relationship between seismic factor on the ground and cost of seismic upgrading, and that between improvement ratio of seismic performance and cost of seismic upgrading are calculated using “dominating damage modes” and ”improvement ratio per unit cost of seismic performance” based on the fault trees. Hence the total cost of seismic upgrading for all the facilities is calculated by summing up the upgrading cost for every “dominating damage modes”.

3. PREPARATION OF FAULT TREES IN SEISIMIC ASSESSMENT

In this study, “Outline of assessment method” proposed in the previous section is applied to a typical equipment, and its procedure until the Step 5) “Preparation of fault trees for each damage level” is defined as follows.

(1) Setting of damage levels and selection of subject equipment

The case example of damage level evaluated by seismic performance from the standpoint of productivity is shown in table-1. In this table concrete examples of seismic damage for the subject equipment are specified. In this study a skirt-supported tower, which is typical equipment in chemical plants, selected as subject equipment. The drawings of the equipment are outlined in figure-2

(2) Extraction of damage modes and their seismic factor on the ground

"The Seismic Design Code of High Pressure Gas Facilities in Japan (Revision of notice No.143, Ministry of International Trade and Industry), called as "Seismic design notice, hereinafter" "is applied to this equipment, so its damage modes shall be "required to be checked by ultimate plastic deformation design method defined in Seismic design notice". The allowable values of damage modes are given as the allowable plastic deformation ratios based on ultimate plastic deformation design method.

Table-1 Definition of damage level

Damage level / Items	Damage level 1	Damage level 2	Damage level 3	Damage level 4
Extent of deformation	Elastic displacement under yielding point	Non-elastic displacement slightly beyond yield point	Non-elastic displacement below twice of yield displacement	Non-elastic displacement below allowable non-elastic displacement (limitation of preventing corapse and leakage of contents)
eration condition	Continuing operation	Emergency shutdown Short term of shutdown Resume operation after partial repair	Emergency shutdown Long term of shutdown Resume operation after the whole repair	Emergency shutdown Irretrievable breakdown
ree of damage Example, etc. j	Damages not affecting operation slight deformation of base plate, stc. j	Recoverable damage with minor maintenance and repair The whole repair can be suspended until shutdown maintenance)	Non-recoverable damage without major maintenance and repair Minor crack of foundation, slight deformation of skirts, etc. j	Non-recoverable damage requiring repair cost more than replacement current cost Non-elastic deformation caused by buckling of bodies of towers j
udgment on necessity f repair, estimated term shutdown Technical necessity j economical necessity n	Operable without repair, shutdown is not required. No emergency response required.) No maintenance cost required n	Operable with minor repair, early re-start is possible. (Ergent repair not required.) Minor cost required for maintenance. n	Operable after repair of 3 months shutdown Ergent repair required j Considerable cost required for maintenance n	Repair not fessible Replacement j Replacement current cost required. n

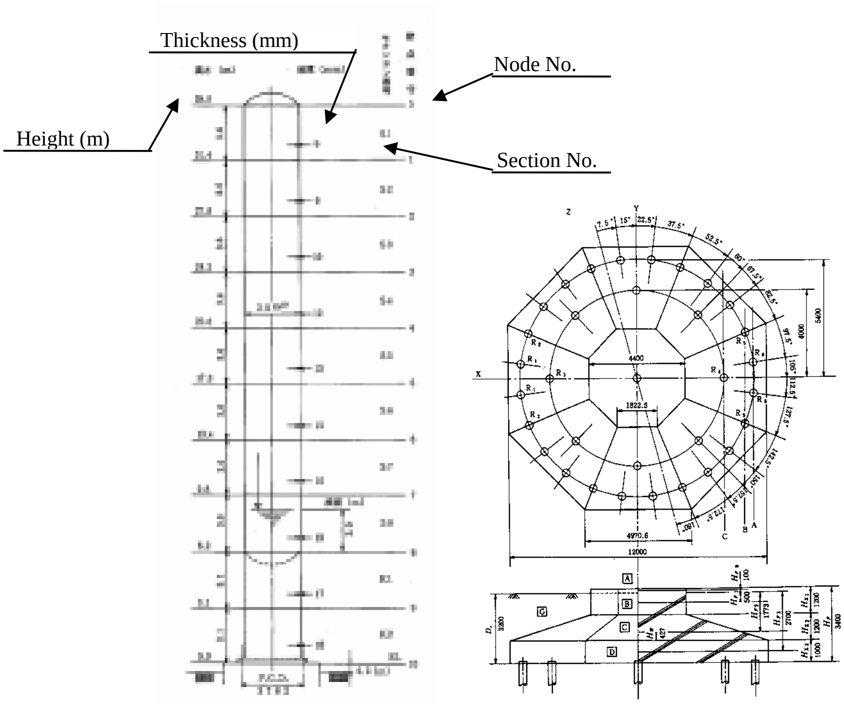

Fig-2 Outline drawing of a skirt-supported tower

Allowable seismic factor on the ground concerning each damage level for each damage mode will be calculated using the assessment method of level 2 seismic performance in accordance with the Seismic design notice. Specifically the method of response analysis applied for the tower and foundation is “energy method” of the Seismic design notice. Ultimate plastic deformation design method of the “energy method” is applied to the tower, and yield strength design method is applied to the foundation.

The procedure of implementing the assessment in this study is summarized as follows.

First, horizontal seismic factor on the ground is assumed, seismic response analysis using the seismic factor is performed, and response plastic displacement ratio of selected components of the tower and loading data for foundation are calculated. Second, response value of foundation is calculated considering the loading data and seismic load acting on the foundation. Concerning foundations, the proportion of the response value to the allowable value obtained by allowable stress design method, which is used in evaluation of the level 1 seismic performance in accordance with the Seismic design notice, is defined as response plastic displacement ratio. As a result, allowable seismic factors on the ground of the tower and the foundation of each damage modes at each damage level are calculated as values when the response non-elastic displacement ratios reach the allowable ultimate plastic deformation ratio.

Table-2 shows the calculation results. In this table results of evaluated components corresponding to selected damage modes of the tower and the foundation are presented.

Table-2 Seismic factor on the ground for each damage mode

Damage modes \ Calculation Values			Seismic factor on the ground			
			Damage level 1	Damage level 2	Damage level 3	Damage level 4
mage mode of tower	Yield related to tension yield of body		0.69	0.92	1.42	1.71
	Yield related to compression buckling of body		0.49	0.58	0.61	0.86
	Yield related to compression buckling of skirt		0.46	0.56	0.67	0.82
	Yield related to tensioin yield of anchor bolts		0.62	0.83	1.03	1.48
	Yield related to bending yield of base plates		0.45	0.53	0.65	0.78
Damage mode of foundation	Push reaction of piles		0.62	0.79	1.03	1.34
	Pullout reaction of piles		0.46	0.49	0.55	0.62
	Stress at compresion side of edge in piles		1.54	1.91	larger than 2.40	larger than 2.40
	Stress at tension side of edge in piles		0.78	0.82	0.87	0.95
	Shear stress at bottom of footing	Piles inside (C section of foundation)	0.34	0.51	0.70	0.94
		Piles midway (B section of foundation)	0.94	1.16	1.49	1.91
		Piles outside (A section of foundation)	1.74	2.08	larger than 2.40	larger than 2.40
		Piles at ouside of pedestal (Vertical section at outside surface of pedestal)	0.66	0.83	1.09	1.42
	Rquired reinforcement volume at top of footing		0.32	0.35	0.40	0.47
	Pullout force of anchor bolts		0.32	0.37	0.44	0.54

(3) Evaluation of seismic fragility

In this section fault trees at damage level 1 and 4 are shown figure-3 and 4 respectively.

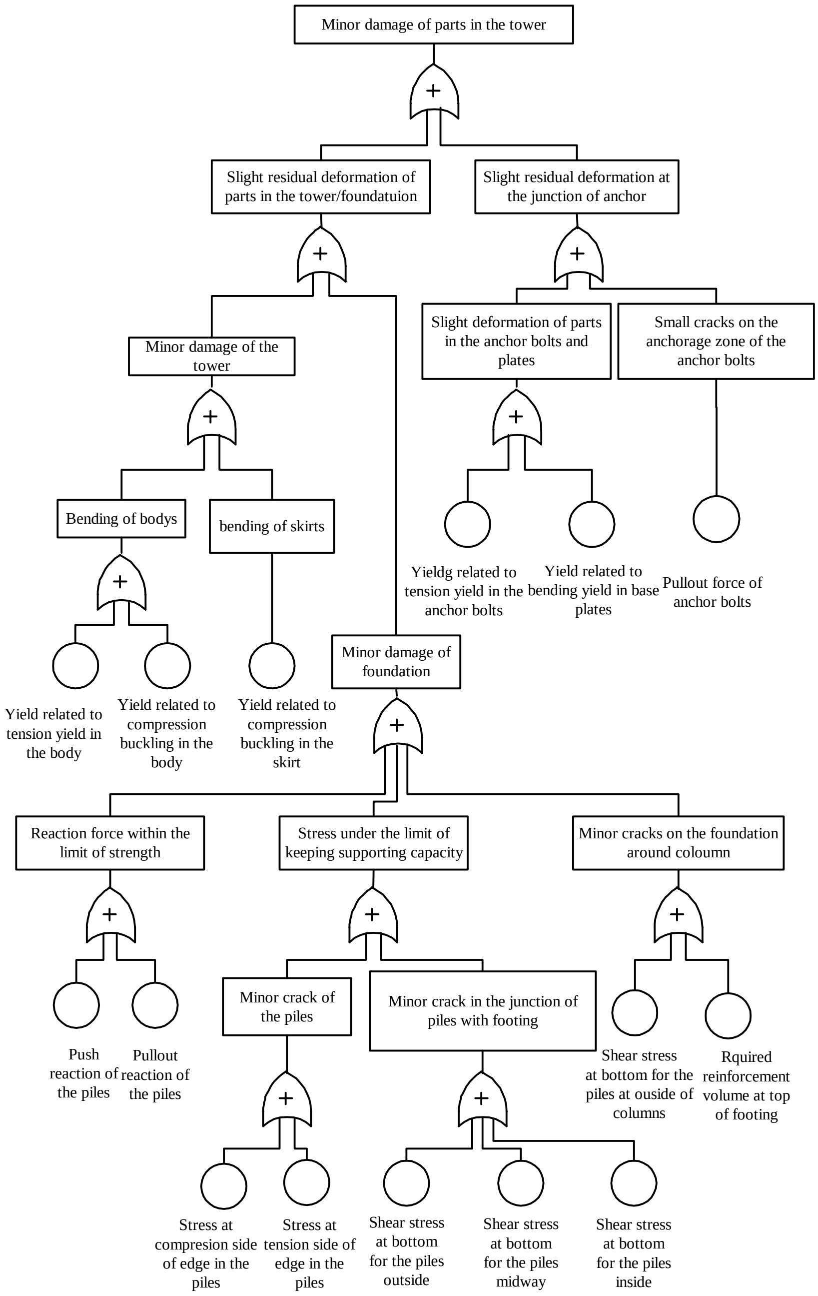

Fig.-3 Fault tree of a skirt supported tower at damage level 1

In this fault tree fundamental events are assumed to be damage modes as described in the previous section, and intermediate events are assumed to be damage of tower body, damage of foundation and piles supporting the tower, and damage of the anchor bolts connecting the tower to the foundation and its anchorage part of concrete. Damage event of the tower is mainly classified from the viewpoint of the residual deformation caused at seismic events by assuming damage condition. Because concerning towers and tanks in chemical plants facilities excluding flat-bottomed cylindrical storage tanks, many recorded cases of liquid and gas leakage accident at seismic events were caused not by cracking in the body, but by relative displacement between.

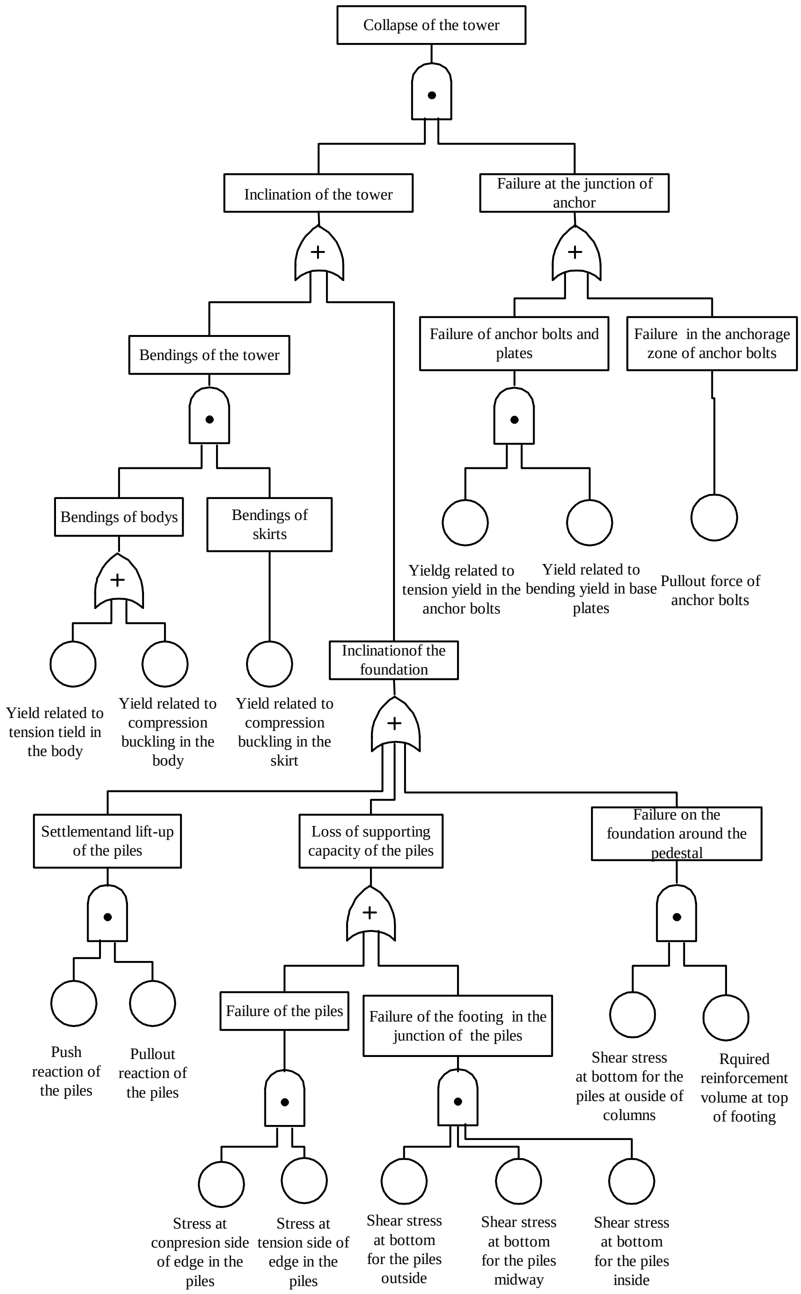

Fig.-4 Fault tree of a skirt-supported tower at damage level 4

(4) Discussion

For the definition of damage levels in the table-1, judgment on necessity for repairs and estimated terms of repairs are proposed based on the studies on the occurrence and period of shutdown caused at seismic events referring to the recorded damage at seismic events and “Guidelines for the Seismic Design of Oil and Gas Pipeline Systems”[5)].

The skirt-supported tower used for the fault tree analysis is a good example of maintaining sufficient seismic performance. As shown in table-2, the seismic factors on the ground range 0.32-1.73 at yielding deformation levels (damage level 1), and Exceed 0.47 at allowable plastic limit levels (damage level 4). However old existing facilities constructed before 1981, when the former seismic design notice of “the Seismic Design Code of High Pressure Gas Facilities in Japan (Notice No.515, Ministry of International Trade and Industry)” is applicable, would not be expected to hold the same seismic performance as this example.

The fault trees shown in figure-3, 4 are developed based on setting the degree of damage of the equipment at each level and on estimating the damage modes affecting the damage.

As a result, fault trees are constructed to indicate that the damages at level 1 are associated with many damage modes, and that the damages at damage level 4 are largely impacted by a limited number of modes assumed to be related to a major damage.

4. CONCLUSIONS

This study intends to develop an assessment method that enables seismic risk management with an emphasis on ensuring of productivity of existing chemical plant facilities.

In the assessment method proposed in the study, a framework of evaluation is presented, which includes setting of damage level considering the productivity, damage modes, developing of fault trees, and building the relationship between costs of seismic upgrading and improvement ratio of seismic performance. Then as a case study, this method is applied to a skirt-supported tower, and setting of damage level considering productivity, and specification of damage modes, and development of fault trees are practiced.

The following findings are obtained throughout the study.

a) When seismic upgrading considering the productivity is studied, the assessment method which enables to provide necessary information in order to decide the target level of seismic performance and policy of seismic upgrading using the limited investable budget is proposed.
b) A case study of defining on damage levels, which consider extent of deformation, operable condition, degree of damage, and judgment on necessity of repair, is presented.
c) The damage modes based on the concept in accordance with the Seismic design notice is proposed.
d) Seismic factors on the ground of each damage mode at each damage level are calculated as an indicator of strength against seismic ground motion, using response analysis in accordance with the design method described in the Seismic design notice.
e) In this fault trees at each damage level appropriately selected the AND gate and the OR gate, are developed.

This study of the skirt-supported tower based on this proposed assessment method will be continued for further refinement. It will include confirmation of this assessment approach being applicable for other equipment, and extension of the study on the scope of application of this approach being widened from single equipment to unit process, and to total plant facilities.

By this methodology, when considering the seismic risk of the total plant system from the standpoint of corporate management, it will aim to provide information for decision-making in implementing seismic upgrading of the chemical plant facilities focusing on maintaining its productivity.

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