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ON A CONCEPT OF AIDING ANTI-EARTHQUAKE DESIGN BY A COMPUTER FOR INDUSTRIAL CRITICAL FACILITIES

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SUMMARY

This paper deals with some concepts for aiding the anti-earthquake design of industrial critical facilities, such as nuclear power plants, petro-chemical industries and so on. The configulation of those facilities is complicated compare to ordinary structures. Therefore, it is difficult to establish good, adequate analytical model for their design. It is observed that many examples of failures were coming from design engineers' error or mis-judgement for modelling.

To avoid such trouble, some aiding systems for design engineers should be established. The fundamental concept of them, with examples of systems which implimented the authors' group will be discussed.

INTRODUCTION

The shapes of components in industrial facilities are very complicated for modelling compare to ordinary building structure, to compute their vibration characteritics and responses to a certain earthquake event. As the authors described on the difficulty of modelling in the previous paper (Ref. 1), the design engineer should choose the adequate dynamic model of the component which is designed seismically. For this he should know the details of the failure modes of them, especially, critical facilities to the public and environment. In general, those facilities are controlled by various regulatory codes like ASME Boiler and Pressure Vessel Code or MITI (the Ministry of International Trade and Industry in Japan) Order. Therefore, the engineer must have various kinds of knowledge on structural engineering, chemical engineering, nuclear engineering and others as well as earthquake engineering and the field experience on failures of them by past earthquakes.

To cover the knowledge and ability of engineers working in this field, the help of a computer system is necessary. This paper deals with several topics for a new Computer Aided Engineering in this field.

MODELLING FOR ANTI-EARTHQUAKE DESIGN

A type of an analytical model for the design analysis are selected according to the required acculacy and its shape or configulation as shown an example in Fig. 1. The

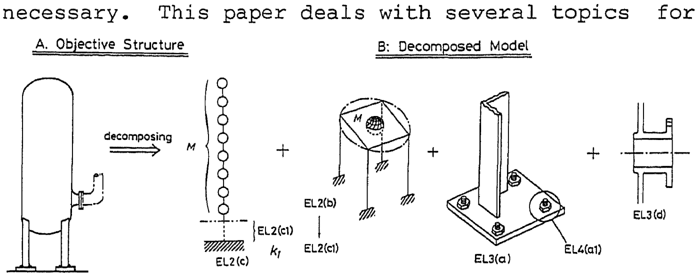

Fig.1. Decomposition of Structure to Analytical Model; Leg-supported Vessel

choice of the degree-of-freedom is also important such as one, two or three dimensional model, and also a shear force only or a force-and-moment model. This might be called the level one model (EL1 in Fig. 1). That is, the main part of the model is a lumped mass model. The next step is how to decide the mass value and spring constant of each section. Especially, it is difficult to decide the leg-section (EL2 in Fig. 1). The authors often mentioned in various occasions (Ref. 2). For example, a model of a leg-supported vessel is chosen often by mistake as a single beam, but, actually four legs behave independently as four beams. The difference of the over-all vibration characteristics is not so small between these two models. The decision of the stiffness k_1 is a "EL 2" modelling. Soil-structure interaction of its foundation are also one of EL 2 modellings. In this case, those values may be expressed by an impedance matrix as the function of the exciting frequency.

As already mentioned, a leg-supported vessel is decomposed into EL 3 or EL 4 in Fig. 1. Upto level three models, it might be an elastic model, if it doesn't include non-linear components, like rattling, gap, friction and so on. EL 4 model includes elasto-plastic, cracking, rupturing behaviors, and can be expressed by a non-linear finite element model. We often observed a failure of leg-support vessel in a curious way. This type of failure became famous through the report (Ref. 3) on San Fernando earthquake. The authors observed it in another earthquake, Coalinga-1983. But the failure process of anchor bolts are related to this mode, and it leads to modelling in EL 4. The ratio of over-turning moment to side-shear force is one of significant parameters for this failure mode. These steps are difficult to be included in its modelling, but if the anchor bolts would not be failed, such a type of analysis is not necessary.

If an engineer will be asked to design a leg-supported vessel, he should know these facts, which can be expressed by an event flow chart as shown in Fig. 2. The authors m·ntioned an idea of this chart in the previous paper (Ref. 2). This event flow chart can be obtained by an expert system as described in the later chapter. Automatic decomposing these models in each levels is subject of the study, but still on the way.

HOW TO Aid DESIGN ENGINEER

An automatic design computer program, especially which has a function of optimal design searching, is no room for an engineer to add his experience on actual damages of a structural system which he is concerning to. But in general, there should be more chance to judge the details based on his experience. In this case, the experience can be expanded into wider ones as shown in Fig. 4, from reports on field survey, summarized books from such reports, text books, manuals, regulatory codes and so on. It is easy to form an ordinary data bank from these data, but it is difficult to form the knowledge to accompish the design procedure. So following steps are considered to aid the design engineer:

1) Event flow chart.
2) Expert system using object-oriented language.
3) Optimal design using expert judgement.
4) Regulatory-code-base computer code.

There are several levels of procedure to support the engineer's design activity based on data and knowledges obtained by the results of past earthquakes, and also design experiences to save the time for repeating the same or similar procedure for designing a particular design object.

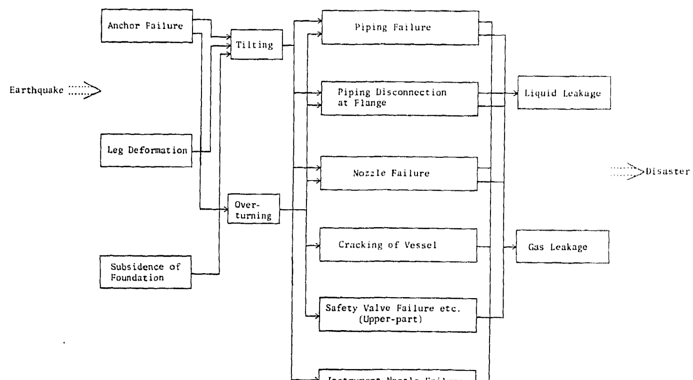

Fig.2. Event Flow Chart

EVENT FLOW CHART

An event flow chart means the flow chart showing the relation of developing an event of failure of a particular portion to failures of other portions. This chart aims to express ensemble of simple relations to a whole picture of the hazard. It starts from an external event, here, of course, an earthquake, and reaches to the disastor as a consequence. Each relation is described *if-then* rule; such as "*if* an earthquake occures, *then a* liquefaction phenomenon will occure", "*if* a liquefaction occures, *then* the foundation will tilt", "*if* the foundation tilts, *then* the vessel will tilt", "*if* the vessel tilts, *then* (a) nozzle(s) will fail" and finally "*if* a nozzle of vessel fails, *then* its content will be diffused into the air".

This series of "*if, then*" statements is one of flows which leads to a concequence as one of hazards expected by an earthquake event. We know various relations expressed by "*if, then*" statements, that is, "rules", based on our experiences as shown in Fig. 3. To compose these knowledge relations into a systematic information, this event flow chart as shown in Fig. 2 is useful. This chart is different from Event Tree or Faulted Tree chart, even it has nodes and links. Links are not accompanied by transfer probabilities. Logics from links to an each node are usually "OR". The logic "AND", that is, "if A and B, then --- " is not so often appearing in our survey results, because a relation is decomposed as simple as possible. And also, other causes may be assumed to occure in 100% probability. It takes an example, "if flamable gas leaking (A) and defused gas consistensy in its detonating range (B) and an igniter existing (C); then the detonation willl occure". Thus we assume that both the conditions B and C would exist, then the condition A, "if flamable gas leaking", is only a cause connected to a result "gas detonation".

The event chart may grow or expand with new knowledges. Therefore, any one wants to add his knowledge may access into the system, and to put his knowledge into it as a new relation or link without the knowledge on the computer program. Two fundamental orders are necessary, that is, to define a new event in an adequate position, and to connect two events as a cause and a result. Of course, their orders such as deleting are necessary, but they are not significant at this moment. This idea was implemented by one of the authors, Fujii, using a concept of pop-up menu and window in 1985 (Ref. 4). This idea came from "SMALLTALK-80", but at that time, the system was not avairable in the authors' laboratory, and the similar system was developed for this purpose.

USE OF OBJECTED-ORIENTED LANGUAGE

SMALLTALK-80 is one of object-oriented languages. As well known at this moment, this type of languages is very convenient for design processes like we are discussing. "Object" acts by a "message" from other objects, and the way of the response of an object is described as "method". Structure of our knowledge is a reflection of a real world, for example, a tower-type vessel. The real world has its structure as shown in Fig. 6 and has the relation to a particular series of knowledges, for example, an anti-earthquake design of the high pressure gas facility. A series of knowledges contains various steps, for example, a categorization of "factor of importance", a selection of types of structures, such as a tower-type vessel, a spherical tank and so on. Then we introduced a frame-type structure. This is a popular technique for arranging the knowledge, but the authors like to mention, its concept fits better to the design procedure or the regulatory code than a rule-base structure. Even though, we must remind that detailed knowledges on anti-earthquake design

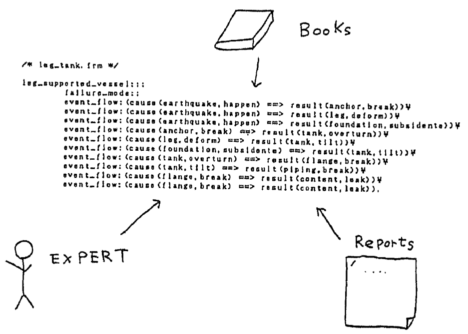

Fig.3. Example of Rules of Failure Mechanism

consist of heuristic knowledges created from rules, as described in the previous chapter, as the event-flow chart.

A concept of design works is considered to fill up the format of design tables according to its structure. A procedure of an anti-earthquake design consists of "classes" as tables for each design steps. Each class contains "method" which explains how to fill up the blank of the table, for example, how to categorize the factor of importance. A set of these classes forms an anti-earthquake design procedure expressed in the regulatory code, but it may include other technical procedures like FEM program to compute the eigen-frequency and vibration mode of a structure.

A design practice starts with sending a message "to generate a new instance" in the first "class". Here, a leg-supported vessel is considered to be a new instance. A leg-supported vessel is a kind of vessels, and a vessel is a kind of anti-earthquake designed facilities, and an anti-earthquake designed facility is a kind of high-pressure gas facilities. The MITI order #515 (Ref. 5) is the design guideline or regulation for high-pressure gas facilities. Therefore, a leg-supported vessel inherits all characteristics of classes above it. This relation is partially shown in Fig. 4, and the concept "inheritance" can save the space for description.

As shown in Fig. 4, the first, second and third classes are common to all types of vessels. So, other-types of vessels are in the similar relations to the leg-supported vessel. Therefore, the characteristics defined in the upper class, for example, "the factor of importance" inherits to the lower classes, and it is not necessary to define or design in the lower classes again. If we proceed to eigen-frequency analysis, models of these vessels are different from each other, and "method" should be described one by one at this step. But, the characteristics difined in the upper classes is still effective there. For example, the method of eigen-frequency analysis depends on its "factor of importance".

This type of the structure of classes extends to all knowledges. Also knowledges indicating a relative relation expressing the structure between one class to another class in a deferent level can be separated from other knowledges belonging to each classes, as a meta-knowledge as shown in Fig. 5. This concept brought various benefits on treating inheritance between classes.

To unify the knowledges from different sources, we need some rules. It is simple to unify knowledges in an each class, but the knowledges containing the relation between different levels of classes, that is, meta-knowledges needs more complicated rules. A "class", or vessel is categorized in a leg-supported or skirt-supported vessel. If one instance is leg-supported one and contains acidic liquid, and the other instance is skirt-supported one and contains high-temperature molteld salt. Both includes different attributes in the same category, therefore, they can not be unified to one. The authors introduced a set of rules for a practical use.

The example quoted above mainly consists of MITI order #515, therefore, "method" in each class is defined by the description in #515. But, as described in Chapter of modelling it is an important step for anti-earthquake design, and it is not so monotonous as the description in #515, and there are

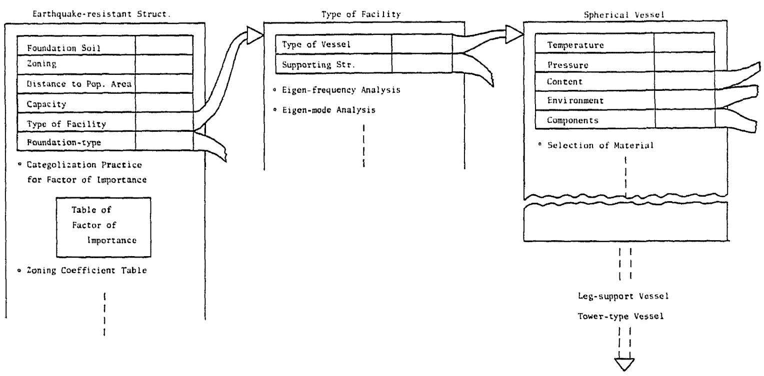

Fig.4. Structure of Knowledge in Computer

variations, and it may be obtained heuristically. This part of the authors' study was implimented by Tsuchino, one of the authors (Ref. 6), using Prolog-KABA.

USE OF EXISTING INSTANCE AND OPTIMIZING THE DESIGN

Process of designing is a synthetic type job against an analytical type job which most of vibrationists are doing. The synthetic type job is more heuristic than the analytical type job usually. For a design work, we try to find a set of design results which consist of various steps, as described in various frames in the previous Chapters. Each class has an instance as a result of design, and the designer wishes that a set of these design steps forms to be optimum in general. If the designer try to find the optimum set without any strategic idea, he must check enormous number of sets of design parameters. To solve this difficulty, the authors introduced the following ideas:

i) Optimizing the design in each frame, if it requires to be optimum,
ii) Finding the local optimum point in a heuristic way,
iii) Optimizing the design in the more practical way than in a mathematical or numerical way.

It is no proof that a set of optimum designs in each step shall be the complete optimum. Also, the optimum point does not form a sharp peak, but also it forms a gentle slope peak in general. Therefore, it is satisfactory to reach to only near-by the summit. To get the optimum solution in a local or individual frame, we need both types of computer languages, that is, a declare-type language like PROLOG and a step-by-step-type one like FORTRAN. Most of processes of solving or finding the optimum point is a kind of numerical calculation and we need a FORTRAN-type language to do it. But it is very important to find an initial value for finding the optimum point to climb up to an adequate local peak, and to save the computer time. To set an adequate initial value is a heuristic work. The schematic flow diagram is shown in Fig. 6.

A typical one is the relation of a capacity of a spherical tank to its geometry. If the design is made for a vessel of particular capacity, that is, an "instance" filling the tables in each "class". The designer wants to design another vessel whose capacity is the same to previous one, all he has to do is to find the example of the same capacity one. In a case of a spherical tank, the capacity is a typical variable not only to express its detailed size, but also material and so on, if the content is the same. Therefore, the case like a spherical vessel can be expressed its attribute by two levels of classes, that is, "capacity" and "content". So if we have many experiences of design, we can find the same capacity one using for a particular content by looking for it in the previously designed instances. This idea may be developed to an optimizing procedure. At far as we have similar examples, we can employ the set of values for the initial values. Sometimes, a set of values, which we often call "slot", has default values. These values are necessary to be changed according to its other attributes, for example, its content. Those facts may expand our idea to introducing more intelligent way to select the initial values.

If we consider the adequate thickness of wall which should be welded in the field, the following knowledges should be mentioned at least:

1) Field welding without annealing should be limited the plate less than 35mm thickness.
2) If a calculated stress σ exceeds the allowable stress σ_a, then the thickness t' should be $t' = \sqrt{\sigma/\sigma_a}\, t$, where t is the original thickness.
3) There are three choises on plate material.
4) Thickness of such plates is tabulated in tables of the Standard.
5) Cost is a function of those parameters, but not so monotonic.

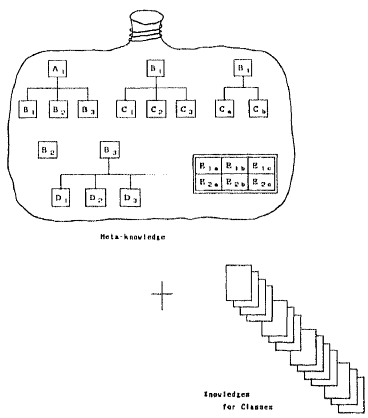

Fig.5. Meta-knowledge and Knowledges on Classes

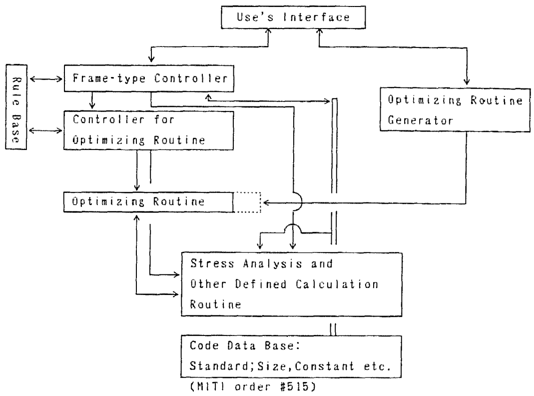

Fig.6. Block Diagram of Optimizing Structural Design using "PROLOG" and "C" Languages with Automatic Code Generation

It should be note that those criteria are not monotonous, for example, even thicker plate is cheaper than a particular size thinner plate which is not common in the market. Rule 2) is commonly used in the design procedure of conventional vessels, but not the exact conpensation. Therefore, an optimization may start from this thickness, after checking rules 1) 3) and 4). The target of optimizing is "the lowest cost" in general. Even if we introduce $W(x)$ by using the internal penalty function method, the constraints are not monotonic in general as mentioned above.

Then, the penalty function $\phi(x, r_k)$ may be introduced, and the condition for the minimum value of $\phi(x, r_k)$ gives the optimum condition. Starting from r_1, try to find the minimum value of $\phi(x, r_1)$, then put a new r_2 which is less than r_1, and try to find the minimum value again, and this procedure continues to be stable for r_k until ϕ will decrease to zero monotoneously.

To save the computer time to find the real optimum, one of the local minimum points is considered to be the engineering optimal point, if it is near to the real optimum point. To select the adequate initial point, the authors introduced a production system to infer a set of initial values from some engineering rules. To obtain the optimum point, one of the conjugate gradient method, Pletcher-Reeves method has been used. As already to be clear, two languages "PROLOG" and "C" are used. This system consists of several blocks of system components as shown in Fig. 8. Some components are written by PROLOG and others are written by C-language, and they communicates as follows:

i) A routine written by C-language is treated as a macro-order in PROLOG system; the length of data is limited.

ii) Data is transferred to disc-memory, and is read out by both systems; it takes longer time for transfer.

The authors employed both methods. One of other features of the authors' system is employing a program generating system for the routine for optimizing in Fig. 8. A part of this program is automatically generated in the routine described C by PROLOG according to the form of internal penalty functions, because the form is depending on the design procedure of an individual design component which we want to be optimized. This system is supported by Quintus Prolog and Unix C in SUN-3, and is implimented by Nagaya (Ref. 7), one of the authors.

REFERENCES

1. Shibata, H. and others, "Damage Assessment of Equipment and Piping Systems under Seismic Condition - Emphasized on Failure Modes", *Proc. of SMiRT-8*, K17/1, 273(1985).
2. Shibata, H., "The Role of Regulatory Documents in Controlling Human Error", ASCE, *Proc. of Modelling of Human Error*, 43 (1986).
3. Gates, W.E. and Blackmon, J.H., A Pictorial Report on The San Fernando Earthquake February 9, 1971, Conrad Assoc., 18, (1971).
4. Fujii, H., An Interactive Programming Environment for Event Flow Chart, Master's Thesis, Univ. of Tokyo (1986).
5. MITI, Anti-earthquake Design for High-pressure Gas Facilities, MITI order #515 (1981) (in Japanese), and SHIBATA, H. *trans.*, Draft of "Anti-earthquake Design Code for High-pressure Gas Manufacturing Facilities", *Rept. of ERS*, No.III-5 (1981).
6. Tsuchino, H., Master's Thesis, Univ. of Tokyo (1987) (in Japanese).
7. Nagaya, Y., Master's Thesis, Univ. of Tokyo (1988) (in Japanese).