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US-Japan Cooperative Research Program (Phase 4): Research project activity of precast seismic structural system (PRESSS) from Japan side

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ABSTRACT: In Japan construction companies are now trying to rationalize construction process and reduce the need of number of workers at construction site. U.S.-Japan Cooperative Research Program on Precast Concrete Building will cover such solution of this problem and new design guidelines . By the examination of the frame work for design recommendation, the scope of research work was clearly defined and understood. Then the details of design recommendation are made based on analytical and experimental research works. In Japan, no design manual for precast member connection exists, which describes the philosophy as well as appropriate example of many kind of connection details. The new manual describes a design methodology of connections which can transfer stresses safely and have enough ductility to cyclic seismic loadings.

1. INTRODUCTION

Most recently, aiming at the savings of shore and reduce construction period, half-precast construction systems, (which use prefabricated beam and half-slab and made them monolithic by topping concrete at the construction site,) have been developed and widely used now. In addition to that, the problem of shortage in numbers of construction workers is much urgent in Japan. Prefabrication is one of the solution of the problem. Some construction companies have already developed precast frame building systems. However the systems are different each other. The precast building systems are required to be checked by the technical appraisal board at present. It causes a delay of construction period and prevent construction of precast building from extensive usage. Further more, lack of detailed design recommendation is an another big problem. Taking into consideration of these Japanese conditions, the development of commonly used design method of precast concrete frame building is indispensable. U.S.-Japan Coordinated Research Program on Precast Concrete Building will cover new guidelines for design and construction. The coordination between United States and Japan will make it possible to develop new guideline for precast concrete buildings more theoretically and more effectively.
This paper discusses the optimum methodology of research development for new design guidelines for precast concrete buildings.

2. EXECUTIVE STRUCTURE

Building Research Institute (B.R.I.), Ministry of Construction has prepared this project one and a half year before its initiation. In order to get an agreement of domestic cooperative research program, and to obtain research investment BRI has discussed the mutual benefits with the authorized bodies of research institutes of builders companies and precast industries, before organizing the project.

Fig. 1 shows the executive structure of Precast Seismic Structural System (PRESSS). In this program, Technical Coordinating Committee decides the targets and their research plan for Japan PRESSS and regulates research methodology with U. S. side. Under this committee, three working group has organized for establishment of design guidelines, design manual of precast joints and specification standard for precast concrete construction. U. S. - Japan joint technical coordinating committee meeting is held every year and the detailed discussion research methodology for the target of this project and technical information exchange are continued thorough this board JTCC - PRESSS.

Besides Technical Coordinating Committee, Research Promotion Panel is also organized in Japan. This panel promotes domestic cooperative research program and arranges the new provisions of the Law basing upon Cabinet Order.

3. DESIGN GUIDELINES

The Japanese building law and accompanying regulations might not be sufficient to protect a building in an intense earthquake by the following reasons;
(1) The Cabinet Order requires that a structure to retain a minimum lateral load resisting capacity at a formation of collapse mechanism. However, the type of a mechanism is not specified nor the deformation at the formation of the mechanism.
(2) The structural calculation does not consider the variation of the earthquake induced stresses from the stress distribution under design earthquake loading. Therefore, some new concept proposed by the Architectural Institute of Japan will be taken into consideration to improve the performance of the

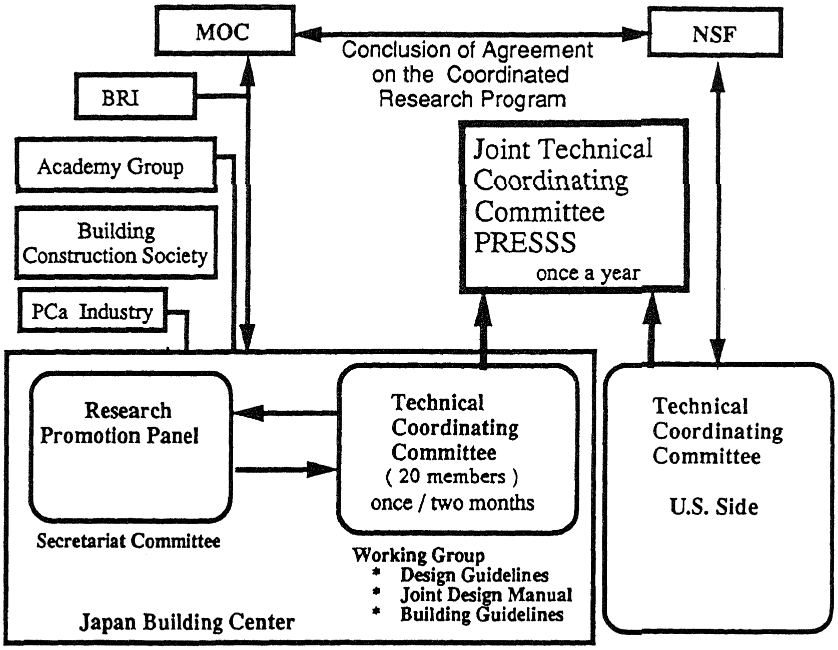

Fig. 1 PRESSS Executive Structure

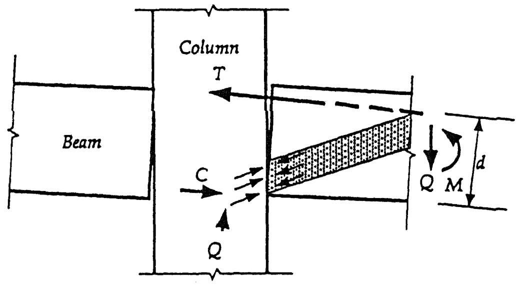

Fig. 2 Concrete Interface of Beam-end at the Face of Column

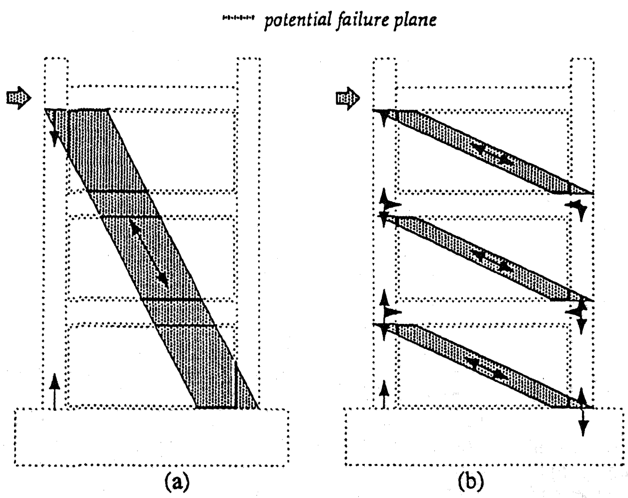

Fig.3 Strut - tie - model for Slender Shear Wall

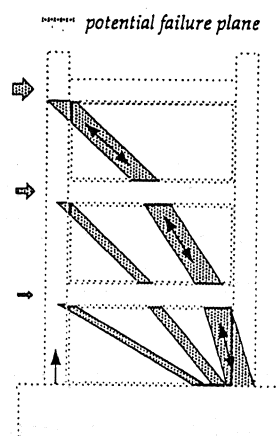

Fig.4 Alternative Strut-tie-Model for Slender Shear Wall

designed structure.

The guideline is intended for use in the structural design of precast reinforced concrete buildings of not more than 45 m in height and of regular structural configuration. The building may be constructed by assembling precast reinforced concrete elements on site; the behavior of precast elements and their connections should be as good as or superior to that of corresponding monolithic reinforced concrete assemblages. The performance of a building during an intense earthquake motion is believed to improve by adopting design concept outlined in the Design Guidelines for Earthquake Resistant Reinforced supports and beam-column joints [2,3,4]. The strut-and-tie-model is examined whether or not it can be used as a new design tool for site-cast connections. If the theory of plasticity is applied to a strut-and-tie-model, the ultimate strength of the member is also able to be predicted by using the lower bound theorem.

Let us consider the beam-end shown in Fig.2. The ultimate state by earthquake load are considered. The angle of a compressive is estimated from the shear-to-span ratio M/(Qd) of a beam as follow.

$$\tan \vartheta = \frac{Q}{C} = \frac{Q}{T}$$

$$= Q\frac{d(1-T/(2bdv\sigma_B)}{M}$$

$$= \frac{1}{M(Qd)}(1 - \frac{T}{2bdv\sigma_B})$$

If the compressive force in the compressive reinforcement is ignored, the condition for no failure along concrete interface is proposed in the following equation.

$$\tan \theta_{critical} < \frac{1}{M/(Qd)}(1\frac{T}{2bdv\sigma_B})$$

where,

T : Maximum tensile force in the tensile reinforcement within hinge zone

b : beam width

d : effective depth of beam

ν : effective strength factor of concrete

σ_B : concrete compressive strength

$\tan \theta_{critical}$: $\tan \theta$ at which the failure model change form failure along the concrete interface to concrete crushing, according to the preparation of interface

Next slender shear wall is reviewed being based on this new design concept. Because of the aspect ratio of the wall, the skew angle of the main diagonal strut to the horizontal joint was large as shown in Fig.3(a). In addition to that, the shear key at interface of wall panel to column was placed in order to enforce the shear transfer at the joint. This type of specimen showed much better performance than squat shear wall. No failure along horizontal joint was observed through recent test results(i.e. Ref.5).

Another strut-and-tie-models can be drawn as shown in Fig. 3 (b). In both cases, the $\tan \theta$ of the strut across the interface is small. The reason that the strength is not lower than monolithic wall can be explained.

Another strut-and-tie-model for the same shear wall subjected to distributed lateral force is drawn as shown in Fig. 4. In this case, the main diagonal strut in the first story is indispensable, and alternative strut can be drawn which transfers the concentrated force applied to Concrete Buildings based on Ultimate Strength Concept [Ref. 1], published from Architectural Institute of Japan (AIJ) in November 1990.

The AIJ Guideline specifies the beam-yielding (weak-beam strong-column) type of yield mechanism to form is a moment resisting frame structure, and assures the formation of the specified mechanism by requiring additional resistance at the region other than specified yield hinges. A precast reinforced concrete building has been believed to be inferior to the cast-in-situ reinforced concrete building in earthquake resistance because the structural performance of a connection of precast elements was not proven to be as good as that of corresponding monolithic reinforced concrete assemblages, to which abundant experimental data have been accumulated. Therefore, a precast concrete building has been designed with an earthquake design load higher than that of a cast-in-situ concrete building. Under these conditions mentioned above, research plans on analytical and experimental studies are examined for optimum methodology on the development of new design guidelines . This design guidelines contain two steps; yield mechanism design and yield mechanism assuring design . In the second step, the magnification due to concurrence of bi-axial earthquake action and dynamic amplification factor considering higher mode in dynamic response. At the same time design limit story drift angle should be defined. This working group chaired by Prof. Shunsuke Otani, University of Tokyo planned systematic case studies . At first three levels of buildings are designed as pilot series of test design buildings ; 20,40 and 60 meters height. Then ,using such test design buildings ,parametric case studies on non-linear static frame analysis and dynamic response analysis were conducted for the direct solution of new design guidelines.

4. DEVELOPMENT OF DESIGN MANUAL OF PRECAST CONNECTION

4.1 Design Concept

The PRESSS Connection Design Manual will outline the methods to design the connection of precast concrete elements to ascertain the reliable performance as good as or superior to the performance of monolithic reinforced concrete assemblages. In order to develop design manual of precast connections , this working group chaired by Prof.Fumio Watanabe ,Kyoto University developed the optimum design concept.

Recently, generalizations of the truss analogy have been proposed in the form of strut-and-tie-models, which treat transfer of stress in a member graphically. This can be applied not only to members but also to the points near concentrated load such as at member second floor level. Thus, it is presumed that the main diagonal strut of the first story will not be able to develop full compressive strength at horizontal concrete interface at the bottom of the shear wall and the failure of first story occur.

Therefore, in design of shear walls, effect of distributed lateral force should be taken into account and it is predicted that the loading condition of contributed lateral force is important factor which should be taken into account to the design.

4.2 Research Methodology of Design Manual

The design tool using strut-and-tie-model is new concept.The reliability and effectiveness for the tool should be examined. However in this field, less research work is available. The necessary research works as follows:

1) Test data of concrete interface to estimate the angles at which the failure along the concrete interface occurs until the concrete strut attains its compressive strength, are very limited. More experimental research on concrete interface are required.Not only the test of interface without crack, but also test of interface with opening and slip are necessary, in order to apply the model to the member which is subjected to cyclic and reversed load.

2) Test data of tensile behavior of connection, in order to assess the capacity of "tie-element, are limited. More experimental research on tensile capacity of connection are needed.The data on the effect of translational displacement along interface to the tensile capacity of connection is also needed, in order to apply the model to tensile force transfer in tensile splice in member which is subjected to large bending moment.

3) The effect of slip at interface on redistribution of internal force should be investigated. Because redistribution of internal force, causes change of designed load path and results in change of mechanical properties.

4) From the viewpoint of strength deterioration during reverse loading,the method to limit deformation at connection will be needed.If the slip at interface remain in some small amplitude, the shear transfer capacity at interface does not deteriorate rapidly. However after large slip along interface, the strength will deteriorate soon.It should be avoided to design a member equivalent to monolithic member.

5) Some reinforcement across the interface may strengthen the interface. But it cannot prevent deformation occurring, because reinforcement would cause cramping force after certain amount of deformation was introduced. The connections which are allowed to occur deformation at connection should be identified from connections which should not deform.

6) Tests of member and subassembledge are needed to verify the strut-and-tie model. By verifying tests, the effectiveness and the reliability will be assured.

There are so many types of test results on precast joint systems. The classification of precast connections is very important job for the new design manual. The purposes of classification of connections are as follows.
1) To find out the necessary research items for the preparation of the Design Manual for Connections without any oversight.
2) To classify the currently used connections into adequate connection categories systematically.
3) To extract the connection elements to be designed. In the Design Manual for Connections, design methods for connection elements in each connection type or group will be recommended because uncountable combinations of connection elements can be possible for connections.

Classification of connections has been conducted on the basis of following viewpoints.

1) Rational classification based on the expected stress transfer through the connection.
2) Easy extraction of design connection elements in the connection.
3) Contribution to the future development of connection method.

5. CONCLUSIONS

1. PRESSS is a big scale research project . In order to develop new design guidelines and connection design manual of precast concrete buildings , new systematic research methodology was successfully selected reviewing each research unit.

2. PRESSS project is U.S.-Japan cooperative research program. The detailed target in each country is different each other. However, the methodology of research development and its discussion can be successfully progressed.

3. New provisions of the Law is now being promoted and arranged basing on the building standard law enforcement (Cabinet Order) from expected research results at the same time.

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