RESEARCH AND DEVELOPMENT PROGRAMS ON TIMBER STRUCTURES IN JAPAN

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ABSTRACT

Recently there have been many projects pertaining to timber structures, mainly dealing with seismic behavior. This paper outlines two main projects that currently are being promoted by several committees within BRI and external to BRI, which report to the BRI project team. They are also being developed collaboratively with public corporations, and international institutes. The Final target of one project is to develop high-performance hybrid timber members and hybrid timber structures, which consist of timber and other materials, to develop the performance evaluation methods for these hybrid timber structures, and to develop the design method for some typical hybrid timber structures. The other target is to develop the seismic rehabilitation system for existing inferior, low-rise wooden buildings. These projects have several goals including developing reliable and economical ways of improving performance of residential wooden houses as well as minimizing the environmental costs in the construction of new homes. The effective utilization of timber is urged from the point of preservation of natural resources and global environment also in Japan.

Key words: timber structures, advanced hybrid timber members and structures, seismic performance, seismic rehabilitation, fireproof performance

1. INTRODUCTION

Recently Building Research Institute is promoting research and development programs on timber structures as one of important tasks. The research motivation is that timber structures represent one of society's largest investments in the built environment; however, one clear issue is the lack of understanding of the seismic behavior of timber structures. The level of confidence associated with the seismic analysis and design of timber structures is much lower than for reinforced concrete and steel structures. As the result, timber structures are very vulnerable during big earthquakes. In a project, which is called "A Research ad Development Project on Hybrid Timber Building Structures" the main objective to improve the structural performance is summarized in the following three items.

1) Develop high performance hybrid timber members consisting of timber and other materials

2) Develop high performance joints to connect timber members ,and between timber and other materials

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3) Develop hybrid timber structures incorporating timber with other types of structures such as reinforced concrete or steel frame.

In this paper, the current activities are summarized.

On the other hand, it is very important to improve seismic performance for existing inferior and low-rise wooden buildings in Japan. The project for their seismic rehabilitation has started since 2002. The research review and future plan also describes in this paper.

2. HYBRID TIMBER STRUCTURAL SYSTEM

The effective utilization of timber is urged from the point of preservation of natural resources and global environment also in Japan. And the effective mixture of timber and other materials is expected to extend the possibility of building structures because of the possibility to realize high performance in both structural safety and fire safety. The Building Standard Law of Japan was revised in June 1998 and the potential to accept large-scale and high-rise timber buildings with its provision of performance based code. The objectives of this research and development project are, to develop high-performance hybrid timber members and hybrid timber structural systems, to develop the performance evaluation methods for structural and fire safety of these buildings, and to develop the design methods for typical hybrid timber buildings.

This project started in 1999 as a five-year national project. There are some preceding researches or designs in this area, such as timber beams reinforced by steel or fibers, floor systems with timber and reinforced concrete, structural systems with reinforced concrete or steel core structure surrounded by timber frames, and so on. These preceding researches are, of course, very useful for our starting of the projects. However, one of the most important issues for the structural performance of hybrid timber structure in Japan is the dynamic behavior of the structures against strong grand motions. There are some research needs adding these preceding researches from the point of seismic performance of such kind of buildings.

2.1 RESEARCH PLAN AND ORGANIZATION

2.1.1 RESEARCH ORGANIZATION

Fig. 1 shows the original organization of research program. The members of the research committee are scholars and persons of experience, structural engineers, and from the Ministry. This committee adjusts and unifies all research items of each sub-committee into themes of the project. The sub-committees carry out concrete research and development on hybrid timber buildings. The working groups were established in order to solve efficiently each item of research and development. Until fiscal year 2000, the research committee, two sub-committees, and six working groups were organized and the sub-committee on fireproof stared from 2001.

2.1.2 RESEARCH PLAN

Table 1 shows the annual plan in the every fiscal year. In the first fiscal year several investigations have been carried out to confirm the feasibility and social needs of

hybrid timber buildings and to clarify the final target of this project. And in fiscal year 2000, concrete research activities have been started.

2.1.3 FINAL TARGETS

The final targets in the sub-committee on the member and joint are summarized as:

Development of high-performance and high-reliable hybrid timber members and joints,

Development of general test and evaluation procedures for hybrid timber members and joints,

Development of some design methods for typical hybrid timber members and joints.

The final targets in the sub-committee on the structural systems are summarized as:

Development of the rational and efficient hybrid timber structures,

Development of general performance evaluation method for hybrid timber structural systems,

Development of some structural design methods for typical hybrid timber structural systems.

2.2 RESEARCH THEMES AND TENTATIVE FINDINGS

2.2.1 INVESTIGATIONS

In fiscal year 1999, following investigations were executed to confirm the social needs and the feasibility of hybrid timber buildings.

Investigation of demand for timber-based middle-rise buildings,

Investigation of existing composite timber-based members, joints and structures,

Investigation of patents on composite timber-based members, joints and structures,

Investigation of oversea and international standards and codes,

Review of the background of provisions for timber buildings in Japanese current regulations.

2.2.2 HYBRID MEMBERS

In the WG on Members, hybrid timber members, such as glulam reinforced by steel or fiber, are classified and their performance was roughly evaluated reviewing the preceding researches. And the theoretical equations to predict generally the strength and equivalent stiffness were derived. Now a series of static loading tests and creep tests on several types of hybrid beams are prepared to validate the theoretical equations. Table 2 shows the outline of the test plan.

For the evaluation of structural performance and the design methods of these members, probabilistic approach seems essential due to the variability of properties in timber-based materials.

2.2.3 JOINTS BETWEEN MEMBERS

Joints between timber and steel, between timber and reinforced concrete and joints between hybrid timbers are treated in the sub-committee. Additionally, timber joints using some new materials, such as carbon fiber, are also investigated. At first, classification of these joints were made according to the location in buildings, component materials, the stress transferred and so on.

In hybrid timber buildings of dual structure type, joints with glued-in rods seem effective joints to connect timber and other materials. And in hybrid timber buildings such as middle rise office buildings, the stress level may be higher and more effective timber joints will be required. Carbon fiber sheets or other

materials can be used for the reinforcement to prevent the rapture perpendicular to grain. Some series of tests on some types of joints to connect timber and reinforced concrete and some joints reinforced by fibers, rods, steel plates or timber-based materials are now prepared for tests.

Although creep behavior of these joints is important problem for the structural performance evaluation and design, there are not so many researches on this matter. Now the prediction method of the creep deformation and the test plans are discussed in the WG on joints between members.

2.2.4 JOINTS BETWEEN STRUCTURES

Joint system between structures is essential research theme for the development of dual structure systems. The WG on joint between structures first picked up the problems which occur in the joints between structures, such as deference of creep behavior, deference of shrinkage, deference of structural behavior against lateral load, problems due to condensation on the surface of concrete or steel, and so on. Next the stress types and stress levels were investigated for some particular structural systems, and the effective joint details were discussed.

2.2.5 FLOOR SYSTEMS

The WG on floor systems deals with various kinds of floor systems, which are acceptable for hybrid timber structures, such as timber beams with plywood, timber beams with reinforced concrete slab, timber deck, and timber deck with reinforced concrete slab. In the WG these floor systems were classified and the performance of structure, fireproof, sound insulation, etc. were roughly discussed.

For structural performance of floor systems, not only the strength and stiffness against vertical load, but also the shear strength and stiffness in plane are discussed considering the structural function as diaphragm against wind and earthquake load. This function is important especially, for example, in the structural design with reinforced concrete core systems later mentioned. And the distribution of design earthquake load for these buildings is an important research theme. Some studies using time history analysis considering shear deformation of horizontal frames are executed to obtain proper earthquake design load. There are not so many preceding researches for the shear stiffness and strength in plane of floor systems. Fig. 3 shows the plan of shear loading tests on some floor systems.

2.2.6 DUAL STRUCTURE SYSTEMS

Dual structure systems are considered to be feasible hybrid timber structures. Fig. 4 shows some conceptual models. As a case study, building design is now tried on three types of buildings, which are reinforced concrete core system, reinforced concrete shear wall and timber frame system, and system of timber frames surrounded by steel frames. This case study is useful to figure out the image of target hybrid timber structures, and to find out the problems for structural performance evaluation and structural design methods.

2.2.7 TIMBER BASED STRUCTURE SYSTEMS

Timber-based systems includes two types, one is the structure system using hybrid timber members and joints and another is the

combined system with different types of timber structures, such as wall system and frame system. In the WG on timber-based systems, these hybrid systems were classified and the problems for structural performance evaluation are drawn out and arranged.

3. SEISMIC REHAVILITATION OF EXISTING WOODEN BUILDINGS

The origin of this project is the collaboration research program with CUREE-Caltech woodframe project, which had been conducted from 1998 to 2001. The objective was to improve the unreliable performance of wooden houses. The following items were examined by integrating current static and dynamic tests, and developing new tests if necessary.

1) Understand the dynamic collapse mechanisms of wooden houses, 1-1) Collect system testing data for analyzing seismic behavior 1-2) Develop three dimensional seismic analysis model (software) for wooden houses

2) Control the catastrophic collapse of wooden houses, 2-1) Develop joint and shear wall systems to avoid a catastrophic collapse 2-2) Evaluate rehabilitation technologies

3) Propose international harmonious testing protocol and evaluation of testing results, 3-1) Testing protocol and evaluation for joints 3-2) Testing protocol and evaluation for shear walls

4) Discuss international harmonious design procedure for wooden house, 4-1) Specification procedure 4-2)Performance-based design procedure

In 2002, the main target was revised in accordance with society problem. The seismic rehabilitation systems are required as soon as possible to ensure life safety. The typical seismic rehabilitation methods and their seismic performance evaluation procedure will be proposed within the fiscal year 2002.

4. CONCLUSIONS

The project on hybrid timber structures started in 1999 as a five-year national project. In fiscal year 1999, some investigations were executed to confirm the demand and feasibility of middle-rise timber-based buildings. In fiscal year 2000, concrete research activities started in six working groups. The main research themes are, general equation for strength and stiffness of hybrid members and joints, prediction of creep behavior of hybrid members and joints, test and evaluation methods for structural performance of members and joints, structural behavior of floor systems against both vertical and lateral load, development of effective hybrid structural systems, and enumeration and solution of some problems in joints between structures. The final targets of this project are to establish general evaluation methods for structural and fireproof performance of hybrid timber buildings and to make some design methods for typical hybrid timber buildings. It will enable to construct middle-rise and large-scale hybrid timber buildings in general and also to stem global warming by minimizing emission of carbon dioxide. It is also important to improve the seismic performance of existing inferior and row-rise wooden structures. Their rehabilitation scheme began from the fiscal year 2002.

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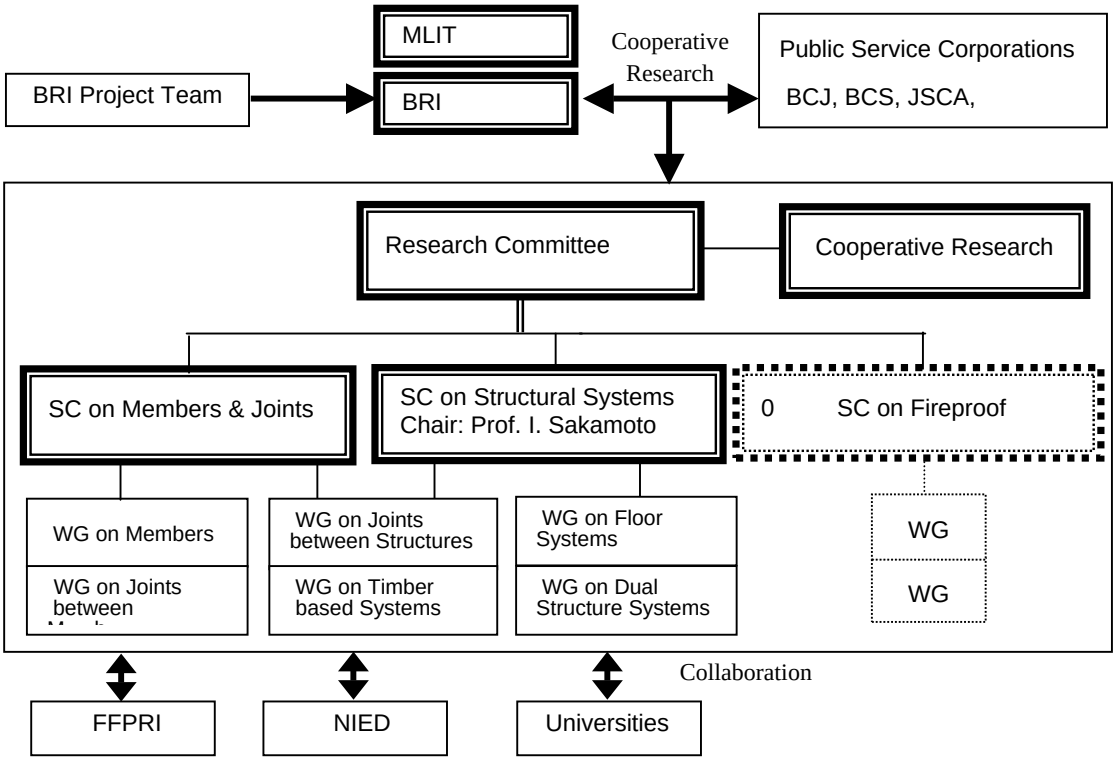


BRI: Building Research Institute, MLIT: Ministry of Land, Infrastructure and Transport, BCJ: The Building Center of Japan, BCS: Building Contractors Society, JSCA: Japan Structural Consultants Association, HOWTEC: The Foundation of Japan Housing and Wood Technology Center, FFPRI: Forestry and Forest Products Research Institute, NIED: National Research Institute for Earth science and Disaster Prevention

Fig. 1Research Organization

Table 1 Research Plan

ITEMS	F.Y. 1999	2000	2001	2002	2003
Development of members & joints					
1) Investigation of current status					
2) Research on mechanical behavior - Creep Tests - Tests on mechanical behavior - Evaluation of mechanical performance					
3) Development and analysis - Proposal of basic concept - Development of members & joints - Tests & analysis					
4) Research on fireproof performance - Clarification of performance requirement - Performance evaluation of members & joints					
5) Design methods & performance evaluation methods - Establishment of basic concept - Proposal					
Development of hybrid timber structural systems					
1) Investigation of current status					
2) Decision of target structural systems - Enumeration of hybrid structural systems - Case study for enumerated systems - Decision of target structural systems					
3) Development and analysis - Basic analysis for proposed systems - Basic tests for proposed systems - Full scale tests for proposed systems					
4) Research on fireproof performance - Clarification of performance requirement - Performance evaluation of proposed systems					
5) Design methods & performance evaluation methods - Establishment of basic concept - Proposal					

Table 2 Test Plan of Hybrid Timber Members

Type of Member		Section of Glulam (mm)	Section of reinforcement (mm)	Connector or Adhesive (mm)	Span of 3-point bending (mm)
Glulam beam reinforced by steel in bith sides		100×200	6×65	2-LS*(d=9, l=75)@70	4,000 and 2,000
				LS (d=9, l=75)@70	4,000
				LS (d=9, l=75)@140	4,000 and 2,000
Glulam beam reinforced by steel in tension sides		100×200	6×65	2-LS (d=9, l=75)@70	4,000
				LS (d=9, l=75)@70	
				LS (d=9, l=75)@140	
Glulam Beam reinforced by carbon fiber sheet in bith sides		100×200	1.4×100	Resorcinol	4,000 and 2,000
			2.8×100		4,000
			4.2×100		4,000 and 2,000
Glulam Beam reinforced by carbon fiber sheet in tension side		100×200	1.4×100	Resorcinol	4,000
			2.8×100		
			4.2×100		

*LS: Lugscrew

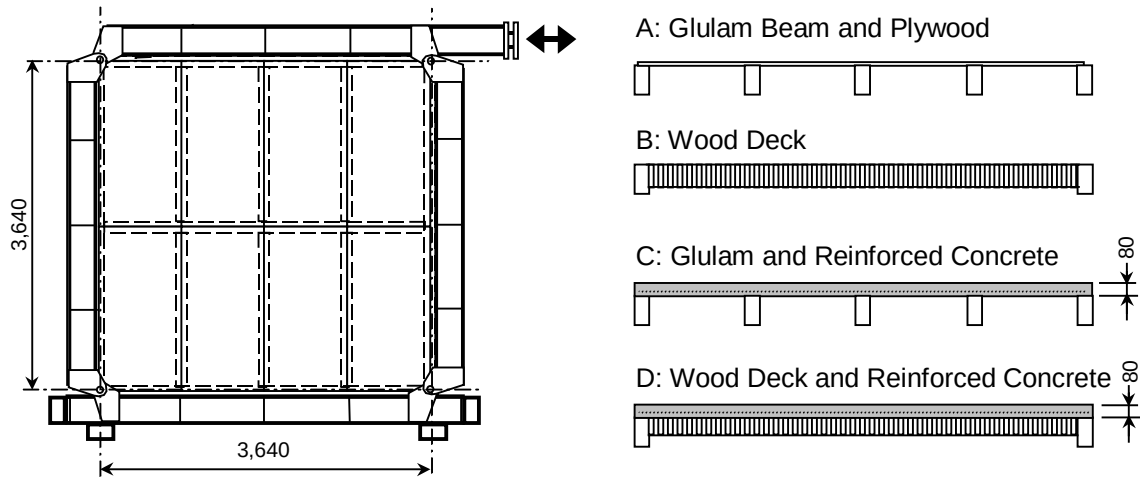
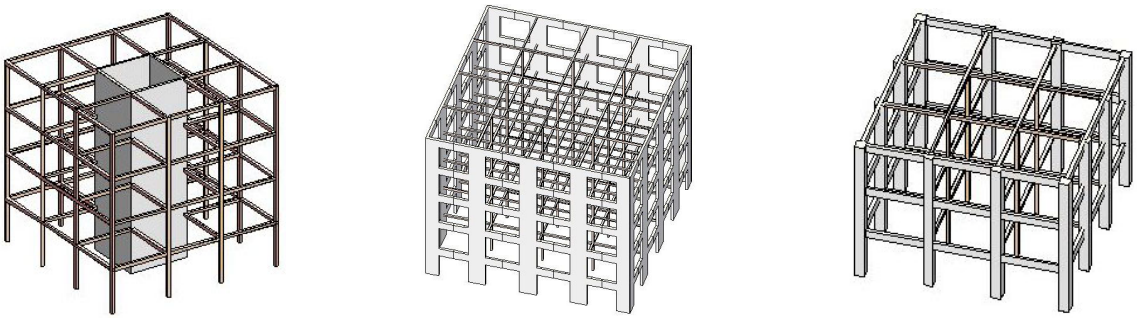


Fig. 3Test plan on floor systems for shear stiffness and strength in plane

a. RC Core & Timber Frame

b. RC Wall & Timber Framec. RC (or Steel) Frame & Timber Frame



d. RC Wall & Timber Floor and Roof

e. RC Wall & Timber Frame

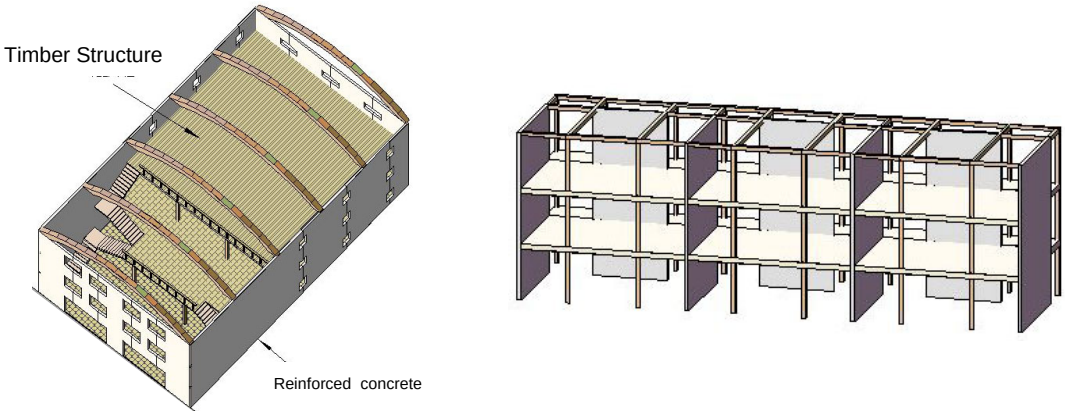


Fig. 4 Conceptual Models of Dual Structural Systems