Structural design considerations in strengthening of timber buildings

Structural Design Considerations in Strengthening of Timber Buildings

Calcul de structures et consolidation de constructions en bois

Statistische Berechnungsmethoden zur Verstärkung von Holzbauten

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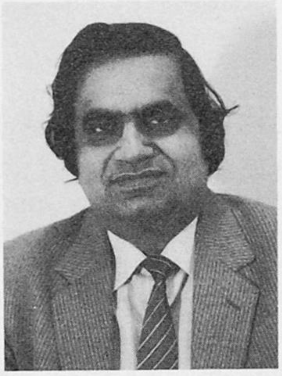

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SUMMARY

Factors affecting the serviceability of timber buildings are reviewed. Also, various aspects of evaluation and upgrading of such buildings are outlined. Structural design considerations in strengthening of timber buildings are discussed briefly. Some examples of strengthening of existing buildings for continued or different use are given. Reliability-based design procedures, which provide a unified approach for structural design standards for various materials, are examined, as they relate to the strengthening of buildings.

RESUME

Les facteurs affectant la serviciabilité de constructions en bois sont passés en revue. Divers aspects de l'évaluation et de la rénovation ainsi que quelques considérations sur le calcul de structures pour des constructions en bois sont exposés. Quelques exemples de consolidation de bâtiments existants en vue du même ou d'un nouvel usage sont présentés. Des méthodes de calcul, basées sur la sécurité et permettant une approche unifiée des normes de calcul de structures pour différents matériaux, sont examinées, en rapport avec la consolidation de bâtiments.

ZUSAMMENFASSUNG

Einflussgrössen auf die Gebrauchsfähigkeit von Holzbauten werden behandelt. Weiter werden Ansichten über die Bewertung und Verbesserung solcher Bauten, wie auch statistische Berechnungsmethoden zu deren Verstärkung diskutiert. Beispiele der Verstärkung von bestehenden Bauten für dieselbe oder eine andersartige Nutzung werden angegeben. Für verschiedene Materialien werden zusammenhängende, auf Zuverlässigkeitsanalysen basierende Bemessungsregeln für die Verstärkung von Bauten behandelt.

1. INTRODUCTION

The reasons for rehabilitation or strengthening of existing buildings can be many, such as: change in the use of building; change in the applicable design code requirements; deterioration of structural members or fastenings; damage to building elements as a result of fire, earthquake, or other like occurrence; historic; aesthetic; etc. As part of the process of strengthening of existing buildings, it is imperative to conduct a detailed structural and materials evaluation. A proper evaluation requires a good understanding of the quality and properties of the materials in the building and of the factors that influence these properties.

This paper provides, very briefly, some highlights of technical aspects of evaluation and structural design considerations in strengthening of timber buildings.

2. FACTORS AFFECTING SERVICEABILITY OF TIMBER BUILDINGS

The task of strengthening of existing timber buildings requires a comprehensive understanding of various factors on the safety and serviceability of these buildings. The foremost of these factors is the total load a building must carry, including not anticipated or non-so-apparent loads in design, such as those of piping, heating/cooling attachments to the structural members, ponding, etc.

Another important factor is the influence of duration of load on material properties. It is well recognized [5, 6, 14] that wood members can sustain short-duration loads of higher magnitude in relation to design loads of normal duration, Fig. 1. To take into account the effect of duration of load, design code [5] and design specification [14] for wood construction classify loads into six categories

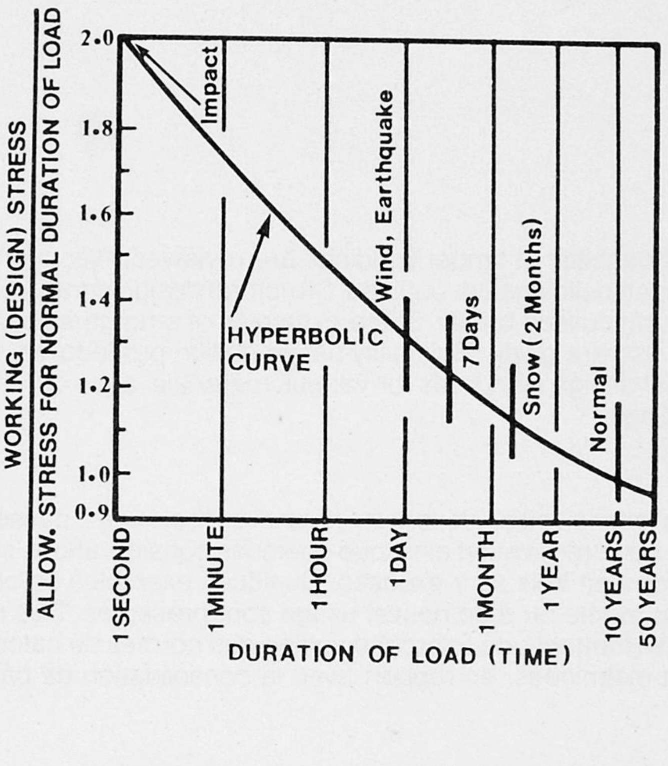

Fig. 1 Relationship Between Design Stress and Duration of Load

according to their duration and provide adjustment factors for use in design for these categories: instantaneous (impact), 1 day (wind, earthquake), 7 days, 2 months (snow), normal (10 years) and continuous (more than 10 years).

Other factors that should be considered are moisture, weather, temperature, chemicals, creep, decay, damage by insects and marine organisms, and fire [1]. Moisture has significant effect on the strength and other properties of wood. Furthermore, free water in wood promotes decay, checking, peeling of paint coatings, loosening of fastenings and corrosion of fasteners. Timber buildings exposed to weather may be subjected to cyclic effect of wetting and drying, which may cause checking in wood. Wood can be attacked by fungi, insects or marine organisms, shortening the useful life of timber buildings. Application of preservative treatment and implementation of proper construction details can enhance the durability of the building [20].

The loss of load-carrying capacity of timber members under the action of fire is the result of two causes, that is the formation of charcoal in the outside portion of the member and the weakening of a thin layer immediately beneath the charcoal. In heavy timber construction, fire resistance is provided by massive wood member sizes and avoidance of concealed spaces in which fire may originate and spread undetected. After fire damage, surface char can be removed by sand-blasting and then the load-carrying capacity of the residual section can be determined [9, 18, 19].

3. CONSIDERATIONS IN EVALUATION AND STRENGTHENING OF TIMBER BUILDINGS

The first step in assessment of the condition of an existing timber building, is a comprehensive visual examination of all building components including fastenings. This inspection also involves species identification of wood members and determination of the extent of deterioration or damage. Many types of equipments and techniques are available for use in the inspection.

Structural evaluation of timber construction requires estimating the load-carrying capacity of: structural components that show sign of deterioration or distress; structural members that will be affected by the strengthening; structural members that are expected to carry increased loading; structural or non-structural components that are affected by earthquake or similar types of hazard loads. There are three basic methods of evaluating structural components and structural systems: (i) Engineering and scientific judgement based on known past performance; (ii) Load tests; and (iii) Engineering analysis. The type of method suitable to a particular building depends on the condition of the building and the nature of the project. Some case histories of strength evaluation of structural wood members and of timber buildings are given in [4, 7, 10, 12].

Strengthening or upgrading of structural systems can be done either by strengthening individual structural members or by adding new structural components. The use of combinations of the two approaches is rather common. For example, a timber column can be strengthened with timber. The strength of such a built-up member can be determined with the aid of efficiency curves like the ones shown in Fig. 2. This figure provides the variation of strength of built-up column to that of equivalent solid column for different bolt spacings for column cross section shown on the graph. Equivalent solid column is taken as a column of same overall dimensions as those of the built-up column. Efficiency curves can be developed for different types and sizes of built-up columns, based on the research by Malhotra and Van Dyer [11].

A building may appear to have performed satisfactorily over the years, but current building code requirements particularly for earthquake loads may require extensive structural modifications. In structural systems for withstanding lateral forces due to wind or seismic ground motion, it is important to consider the manner in which the lateral forces are to be transferred to the foundation of the structure.

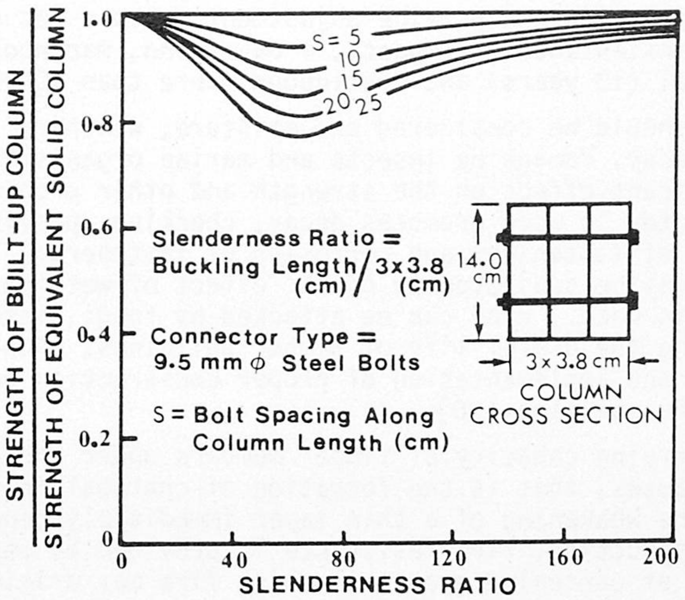

Fig. 2 Efficiency of Bolted Built-Up Timber Columns With Respect to Equivalent Solid Columns, For Various Bolt Spacings

Each structural member must have adequate strength to resist the applied forces as well as be able to transfer these forces to the adjoining elements. Thus, particular attention has to be given to design structural connections so as to ensure integrity of the structure.

There are two basic types of structural systems for resisting forces. In the first system, the lateral forces are resisted by moment connections or knee-braces, Fig. 3. The forces are transferred to the ground through trusses (or girders) and columns. The trusses are designed for forces by the lateral as well as gravity loads and the columns for combined bending and axial loads. The second structural

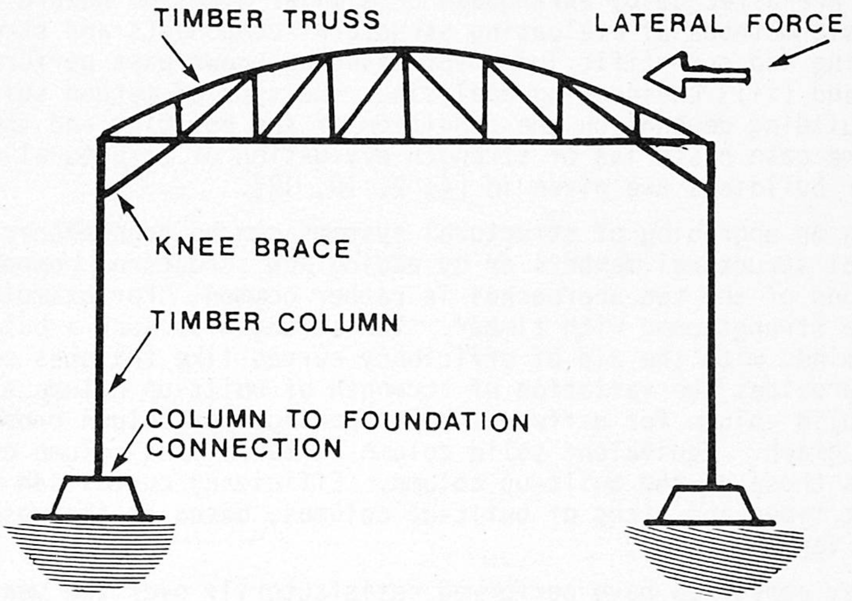

Fig. 3 Knee-Braced Truss Bent - A Structural System to Resist Lateral Forces

arrangement for resisting lateral forces, is shearwall and diaphragm system. A shearwall or diaphragm is plate-type structural element capable of transmitting forces in its own plane. Shearwalls and diaphragms are very effective structural wood systems for resisting lateral forces. Figure 4 shows shearwall and diaphragm action in the distribution of lateral forces on a simple leox-like building. If floors, walls and roofs in a building are to function as structural diaphragm or shearwall, they must be designed adequately to fulfill that role. Care is to be given to adequately reinforce openings in shearwalls and diaphragms with framing members and connections. Diaphragms must be suitably connected to the shearwalls and the entire structure be fastened securely to the foundations to resist uplift forces.

In many instances of rehabilitation or strengthening of buildings, composite structures made of different materials are often encountered. Limit states design, a probabilistic design approach currently under development in Canada, offers a unified procedure for all civil engineering structural standards and thus, simplifies the design and evaluation of composite structures. It also provides a means of incorporating reliability into the investigation of the structure's limit states. A brief description of limit states design, particularly as applied to timber structures, is given in [13].

4. EXAMPLES OF REPAIR, REHABILITATION AND STRENGTHENING OF BUILDINGS

There are numerous methods of repair of timber buildings, such as: replacement of decayed parts; structural damage repair by using mechanical fasteners like clamps, metal bands, bolts, etc.; repair of structural damage by epoxy and other types of adhesives. Some examples of repairs of timber structures are given in [2, 3, 7, 15, 16, 17, 21].

There are many examples and case histories of recent rehabilitation and strengthening of timber buildings, as listed in various publications on the subject. Some examples are illustrated in [4]. The Butler Square Building in Minneapolis, Minnesota, U.S.A., is an excellent example of a warehouse type building into eight

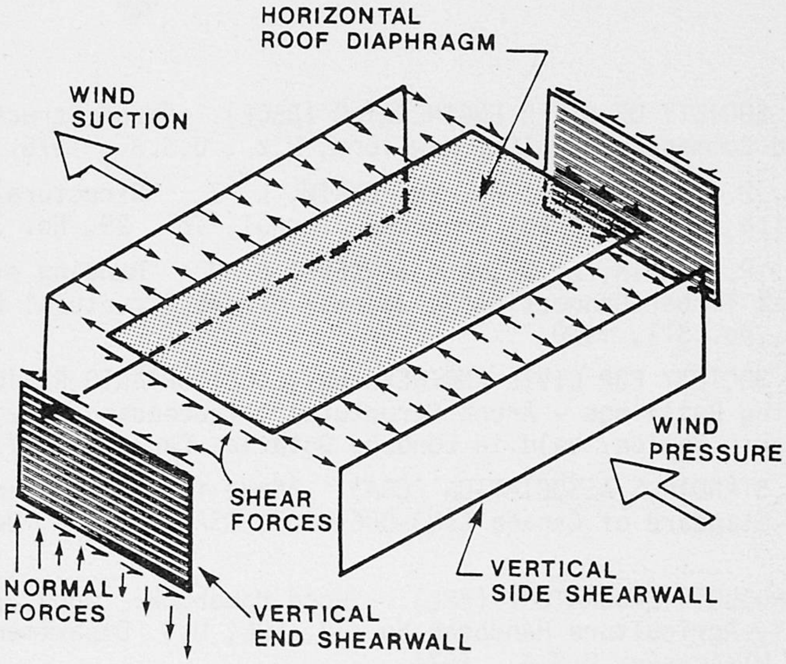

Fig. 4 Shearwall and Diaphragm Action in a Simple Building Subjected to Wind Load

floors of office and retail space [8]. It has been awarded an Honour Award by the Minnesota Society of Architects. The remodelling was accomplished by using heavy timber flooring, solid timber joists and beams of two solid timber pieces bolted together. Exterior bearing wall of masonry provided the major lateral stability of the building. The massiveness of the building (about 46450 square metres) was considered undesirable for its intended use and consequently the concept of atrium was utilized to provide an openness to the interior space.

5. CONCLUSIONS

Wood, a renewable resource, has many inherent advantages for construction applications. It can be used in wide varieties of creative ways for buildings that are not only functional but have aesthetic appeal as well. Many timber buildings of today are innovative structural systems. Examples and case histories of recent rehabilitation or strengthening of timber buildings indicate the versatility of wood as material of construction.

There can be many reasons for rehabilitation or strengthening of existing buildings. Some aspects of evaluation, including factors affecting the serviceability of timber buildings, were reviewed in the paper. Various structural design considerations in strengthening of timber buildings were discussed briefly. With scientific evaluation and investigation and with engineering design, timber buildings can be strengthened to provide many years of very satisfactory performance and durable service life.

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