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Expert System for Seismic Assessment of RC Buildings
Système expert pour l'aptitude sismique de bâtiments en béton
Expertensystem für die Erdbebentauglichkeit von Gebäuden

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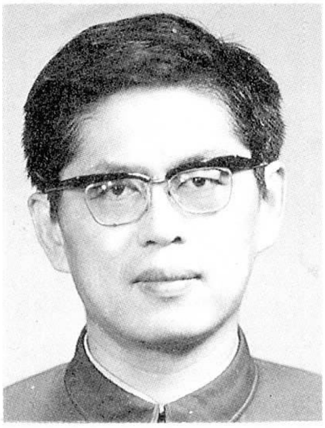

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SUMMARY
The expert system presented has been practically used for seismic resistance evaluation of existing single story reinforced concrete industrial buildings. The paper discusses its knowledge acquisition, representation, architecture, handling of deep knowledge, integration of knowledge base, graphic software and computing programmes.

RÉSUMÉ
Un système expert a pu servir à déterminer l'aptitude sismique des bâtiments industriels existants, en béton armé et à un étage. Les auteurs exposent l'acquisition des connaissances, la représentation, l'architecture, l'accès aux connaissances particulières, ainsi que l'intégration de la banque de données, avec logiciel graphique et programmes de calcul.

ZUSAMMENFASSUNG
An vorhandenen einstöckigen Industriebauten aus Stahlbeton wurde ein Expertensystem zur Ermittlung der Erdbebentauglichkeit eingesetzt. Der Beitrag behandelt die Erhebung der Wissensbasis, die Darstellung, den Aufbau, den Zugriff auf tiefliegende Erkenntnisse, sowie die Integration der Datenbank mit Graphiksoftware und Berechnungsprogrammen.

1. PRELIMINARY REMARKS

The need for diagnosis, evaluation, rehabilitation and retrofit of existing buildings is quickly growing up in many countries in the world. Diagnosis and strengthening of existing buildings are more difficult than design of new buildings, and skillful engineers in the field are lacking. Experience and expertise involving concepts, judgment and inference play important role in the field. Development of the expert system for evaluating seismic resistance of single story RC industrial buildings, SASIBR, is based on symbolic inference capacity of the expert system technology.

Developing expert systems in the field of structural engineering started in the late 70's [1], 15 years later than that in many other fields. This is perhaps because of the following executive characteristics of the knowledge in structural engineering [2, 3], that make building expert systems of structural engineering more difficult than in other fields:

-A deal of important knowledge on structural engineering are in various codes and standards,

-complicated numerical computation is often inevitable in the field of structural engineering,

-A great amount of data is often involved in the field,

-Uncertainty involved with many parameters in the field is more suitable to be described by the probability theory,

-A variety of knowledge in the field leads to the necessity of development of integrated systems.

SASIBR has been developed based on the following principals of practicability that make expert systems vital:

-Integrity of knowledge: Expert systems have to keep complete knowledge necessary for their work. The knowledge on evaluating seismic resistance of existing buildings consists of two parts. The first one is on construction requirements that guarantee these buildings to have reasonable load transferring paths, and on requirements of detailed design regulations that guarantee structural components of buildings to exert their assigned load bearing ability. The second one is on analysis of effects of different loads and check of strength of structural components of different materials. Integration of knowledge makes expert systems able to carry out throughout indoor evaluating work. SASIBR has the both parts of complete knowledge on evaluating seismic resistance of single story RC industrial buildings.

-Authority of knowledge: Knowledge stored in expert systems has to be authoritative in concerning fields, and can be generally accepted by engineers in concerning profession. SASIBR has complete knowledge of concerning provisions of two Chinese nation codes revised recently, i.e. The Evaluation and Strengthening Design Code on Seismic Resistance of Buildings [4] and the Design Code of Seismic Resistance of Buildings GBJ11-89 [5], and their commentaries, as well as explanation on concerning provisions by responsible members of the revising committee.

-Ability to work on the most popular computers and operating systems. SASIBR has been designed to work on IBM PC/AT or compatible computers and under DOS operating system.

-Convenience to be used: SASIBR interacts with users in Chinese. It can display graphically on screen structural models of evaluated buildings, loads, and computed forces, deformations, and safety margin. Its specially designed input unit can minimize user's input effort by five ways. Its execution is suitable to practical evaluation work that different data are input at different stages of evaluation. Junior engineers can use it after a few days training.

-Ability to quickly obtain conclusions: Engineers from a design institute finished by SASIBR evaluation work of a two span buildings and obtained a reliable report of evaluation in one day, tree days less than that needed without it.

After 5 year research and development, and after being tested by first users and improved , SASIBR has been practically applied now. It checks buildings unit by unit and span by span. Its knowledge base can fire external programs and get data from them. When each of its execution ended, SASIBR produces a final report that gives evaluation conclusion with a list of components and connections that should be strengthened. SASIBR includes 400 facts and 600 rules. Its source file consists of 18,000 lines. SASIBR is offered in 5 pieces of 5" diskettes of double density, together with a manual of 77,000 Chinese characters[8].

2. ACQUISITION AND REPRESENTATION OF KNOWLEDGE

2.1 Effects of Earthquakes on buildings

SASIBR holds the data of design seismic intensities of 195 cities and countries in China, with normalized design response spectra from the Code [5]. In addition, it can accept results from special seismic risk analyses.

2.2 Knowledge of Seismic Resistance of Single Story RC Industrial Buildings

This block of knowledge consists of 2 parts. The first part describes the following effects on seismic damage of the whole structure of being evaluated buildings:

-The importance of buildings and potential secondary disaster.

-Harmful situation of site geology, soil characteristics and natural or artificial foundations.

-Vertical and plan irregulation of building configuration. In transverse direction it involves existence of single brick end wall at two ends of a building unit, existence of brick partitions higher than 3 meters transversely filled in bents, existence of unequally spaced columns along column lines in a building unit, and existence of operating platforms rigidly connected to columns. In longitudinal direction it involves existence of side walls of different materials in a building unit, existence of brick walls higher than 3 meters longitudinally filled in column lines, and so on.

The second part of knowledge is main contents of knowledge in SASIBR, that involves the complete knowledge evaluating seismic resistance of components, members and connections of single story RC industrial buildings. Based on different functions this part of knowledge is filled in five sub-bases of knowledge:

-Skylight systems: The most serious damage to single story RC industrial buildings is caused by collapse of RC skylight frames in the longitudinal direction of building unit. This sub-base keeps knowledge on top chords and vertical struts of skylight frames, on vertical bracings of skylight frames, on window frames and concrete panels on skylight frames, and on connections between these members, and between skylight frames and roof trusses, and so on.

-Roof systems: This sub-base keeps complete knowledge on requirements on all members and connections of both of purlinless roof system (with precast RC double tees supported directly on roof trusses) and purlin roof system (with corrugated cement sheets or steel formed deck units supported on purlins). See Fig. 2.

-Walls: Solid brick walls in single story industrial buildings usually do not bear any load from other components, even then improperly designed or located brick walls have made serious damage to the buildings during past earthquakes. Badly located brick walls damaged RC columns, falling down blocks of brick walls smashed lower components and equipments, and near-by buildings, and caused secondary disaster. This group of knowledge includes knowledge on both solid brick walls and precast concrete panels, and also includes knowledge on end walls, side walls, blocking walls and filled partitions. Its structure is showed in Fig. 3.

-Column bracings: Column bracings designed for resisting effects of wind and overhead cranes usually have the ability to bear effects of earthquakes up to intensity 7. In addition of column bracings, brick side walls and columns can also bear effects of earthquakes in the longitudinal direction of building units. Seismic damage of single story RC industrial buildings due to improperly designed column bracings in the longitudinal direction during past earthquakes, therefore, was not very serious. This group of knowledge involves only check of construction characteristics, and does not need dynamic analysis, according to ideas of experts in the field.

-RC columns: This group of knowledge includes RC columns connected to bracings, upper parts of columns supporting roof trusses of the spans of their two sides at unequal heights, and column brackets supporting the lower trusses or crane girders. In many cases, dynamic analysis and strength checking are necessary, and should be kept in SASIBR, and link to the sub-base of knowledge.

-General assessment of seismic damage of spans, units, and buildings: This group of knowledge gives marks on each span, each unit and each building based on the evaluation of the sub-bases of knowledge.

2.3 External programs

Based on the requirements of evaluation of seismic resistance of single story RC industrial buildings, the following 5 external programs are included in SASIBR:

-Data reading program PR: It reads the data necessary for dynamic analysis and strength checking, but not needed by knowledge base.

-Data reading and pre-processing program of bents PG: It makes analytical models of buildings having up to 6 spans after reading data, numbers nodes and elements, condenses masses of blocks of walls, columns or crane girders on proper nodes, calculates loads on column brackets from crane wheels and crane girders, deals with built-up RC columns or columns that have big opens in their webs, and assigns 12 different combinations of dead loads, live loads, snow loads, loads from cranes, and seismic effects, according to the related Code.

-Static and dynamic analysis program of 2 dimension finite element PS.

-Strength checking program of RC and steel components PSA: It is totally based on the recently revised Codes [6,7].

-Graphic display program PP: It displays structural models of finite elements of the bents of being evaluated buildings, loads at the nodes, free vibration mode shapes, computed moments, axial and shear forces on all members of the bents, deformation of the bents, and safety margins of all members of the bents. A menu in PP can help users to do many things.

2.4 Representation of knowledge and Inference

The production rules are used for representing knowledge in SASIBR. Forward chaining and depth first search are used for SASIBR.

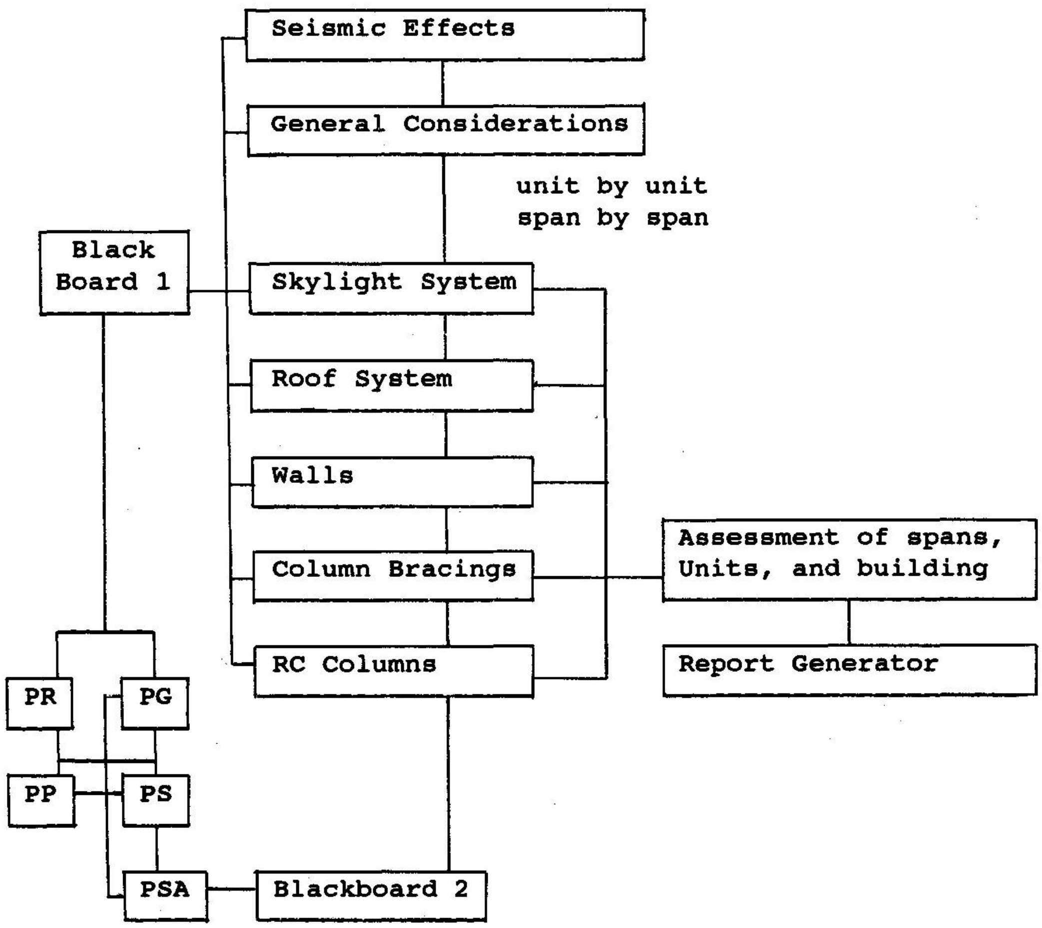

Fig. 1 Architecture of SASIBR

3. ARCHITECTURE OF SASIBR AND ITS KNOWLEDGE BASE

3.1 Architecture of SASIBR

SASIBR has blackboard structure, its knowledge base is divided into 8 sub-bases (Fig. 1). Transferring information between the sub-bases or between the sub-bases and the external programs is carried on by the blackboards.
The knowledge base has hierarchical structure, at the top level is the general considerations, next to the top level are the 5 sub-bases. All of the 5 sub-bases have plenty of knowledge, for instance see Fig. 2 for the sub-base 'Roof

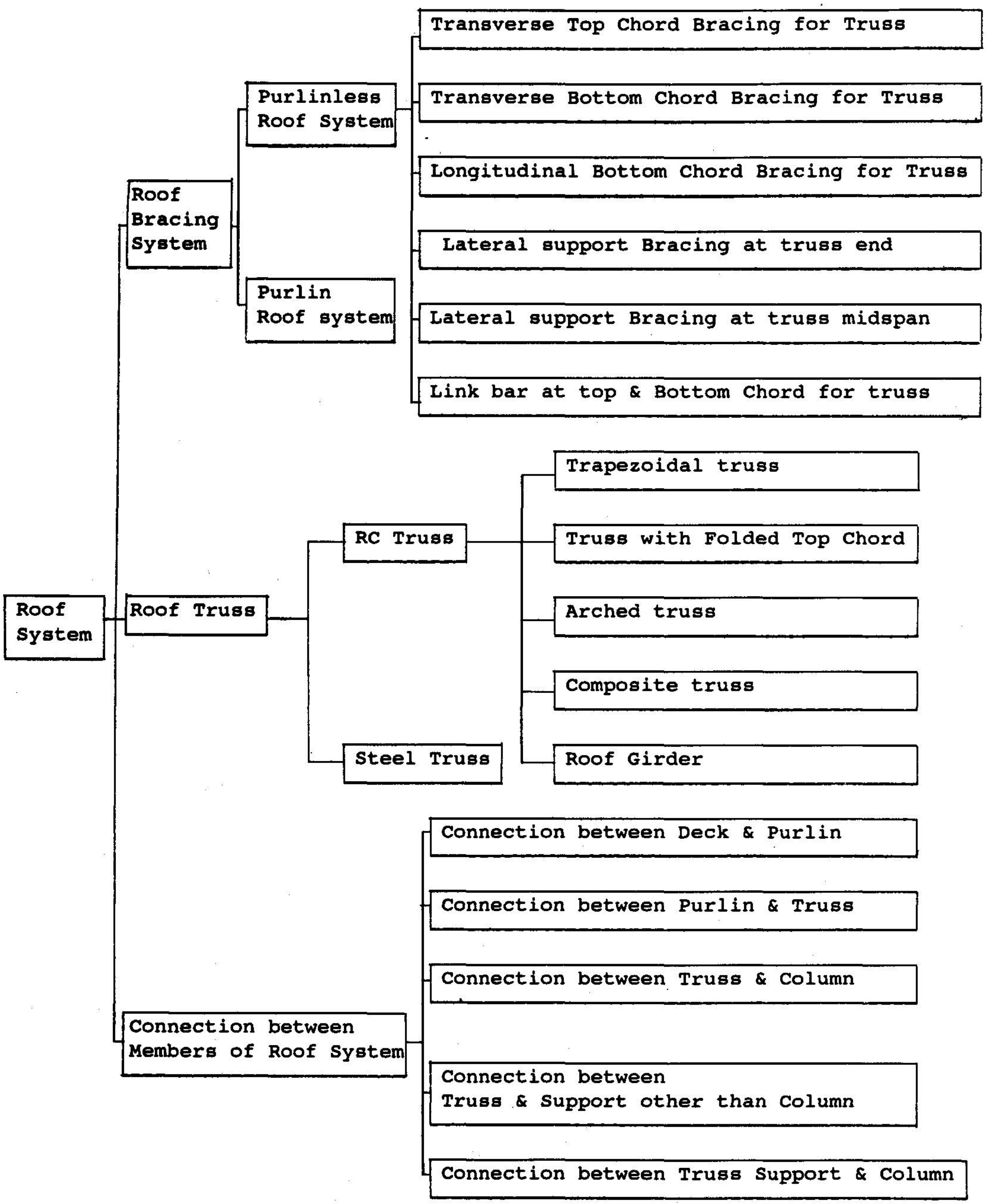

Fig. 2 The sub-base 'Roof system'

System', and Fig. 3 for the sub-base 'Walls', the knowledge in the sub-bases also have hierarchical structure. For instance, the hierarchical structure of the lower sub-bases 'Top Chord Bracing for Trusses' in the sub-base 'Roof System' is showed in Fig. 4.

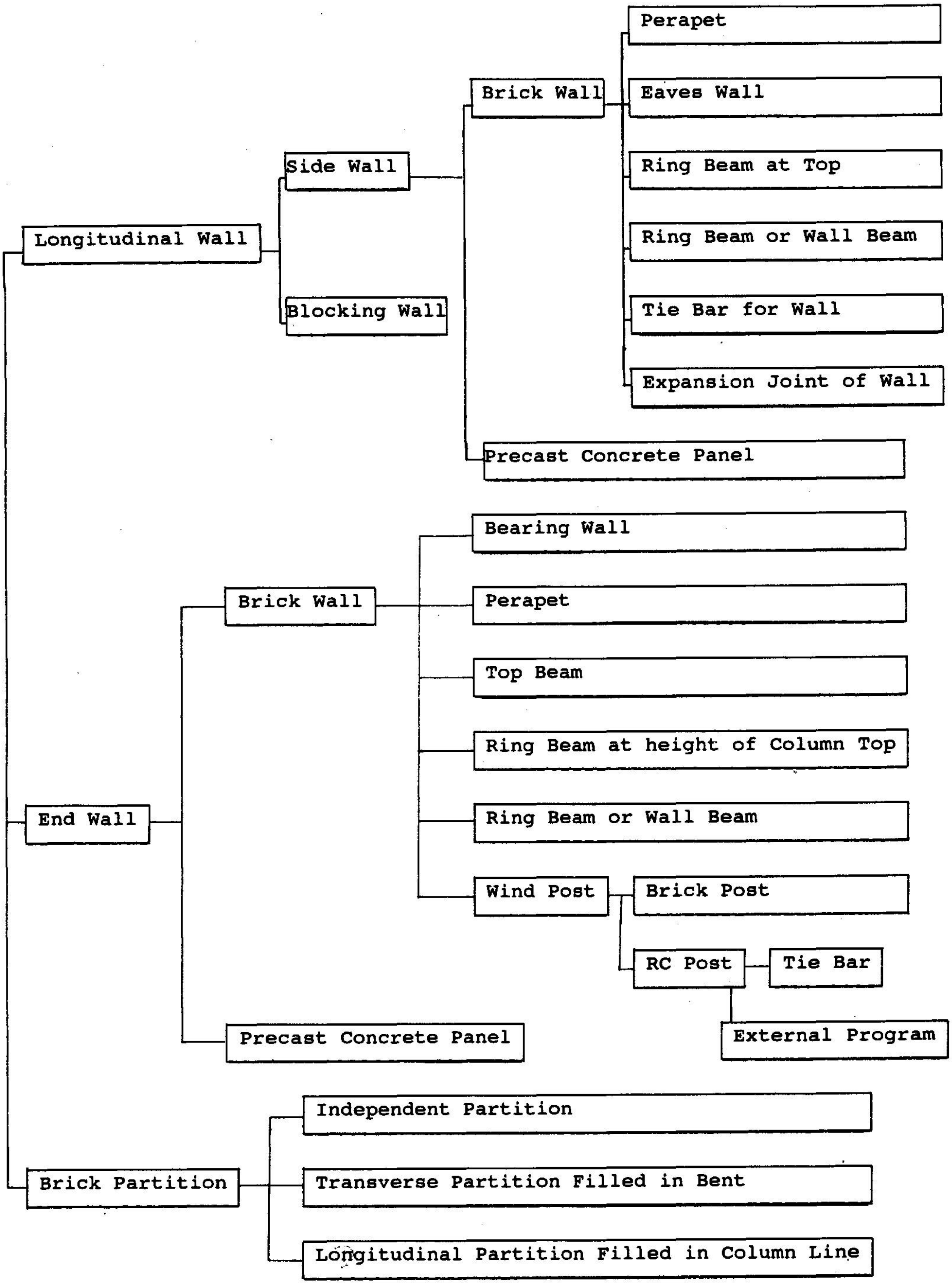

Fig. 3 The sub-base 'Walls'

The context of SASIBR holds all of initial and inferred data and facts such as
'A line of Top bracings for truss exists in each end bay',
'Type of roof truss is Trapezoidal',
and so on.

Every sub-base of knowledge holds knowledge of special area, that is represented by a number of rules. For example, one of such rules,

RULE#
IF Roof system has Purlin,
AND Type of roof truss is Trapezoidal,
OR Type of roof truss is Arched_top_chord,
OR Type of roof truss is Polygonal_top_chord,
AND Intensity is 9,
THEN a line of Top bracings should be set in each end bay.

is in the block 'Layout of bracing' in Fig. 4.

3.2 Implement of SASIBR

The languages of Assemble and FORTRAN are used for developing SASIBR. Designing the blackboards for transferring numerous data is a difficult job. Some available expert system shells, such as INSIGHT2+ is not suitable for transferring such big amount of data. A specially designed manager of data base in SASIBR supervises the blackboards for transferring information.

The following 5 ways are used in SASIBR for inputting data:

-The data base manager generates a list to guide input of data after a few information on general considerations are input. Users can input data according to the list, and avoid spending much time on judging which data should be input and on inputting great amount of useless data.

-Any piece of data can be input by either filling the data list or by answering the screen. Great amount of data is better input by filling the list. During execution, SASIBR will ask users to add some data when needed.

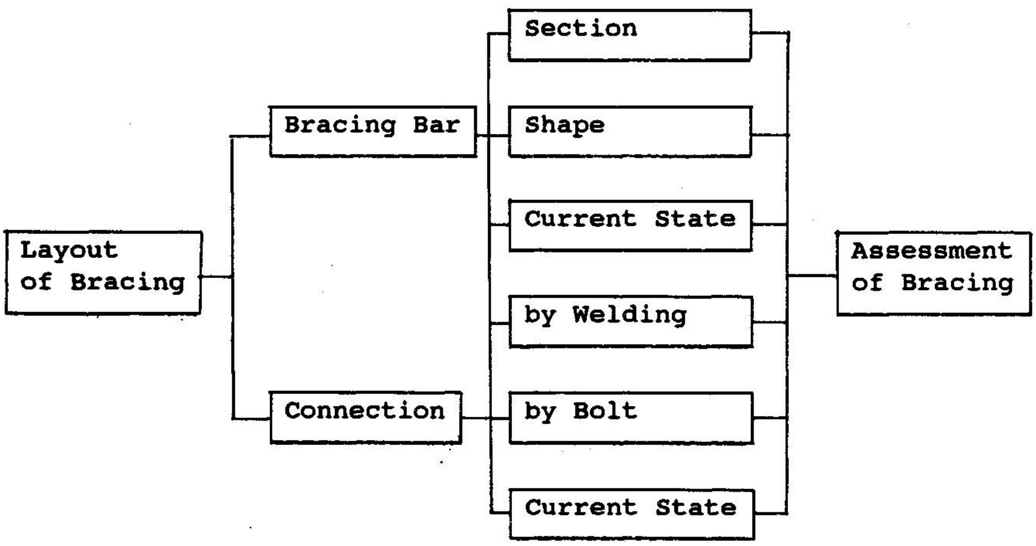

Fig. 4 The sub-base 'Transverse Top Chord Bracing for Truss'

-The data list includes default values of many data. The default values are standard or most common values of data.

-Many mistakes made by users during input are immediately found and shown on screen.

-Data needed by practically evaluating works are from different sources such as documents, drawings, and field testing. And the data input during the earlier stages of evaluation decide what data will be needed for the later stages when practical evaluation works are being carried on. Based on these situation, SASIBR is designed in such a way that its execution can be broken at any step , and then continued after some new data are input or some old data are corrected without loss of any data whether by input or inferred before.

Similarly to practical evaluation, SASIBR evaluates consecutively each span and each unit of buildings one by one. For each span of buildings, SASIBR use the five sub-bases to obtain conclusions. All informations about the conclusions are stored in the context, that will be used for general assessment and the final report.

The data in the knowledge base of SASIBR will be automatically transferred to the external programs when needed. Dynamic analysis and strength checking, however, require more data than that needed by the knowledge base. The programs PG and PR will read that part of data. The instruction how to input those data is in the book 'SASIBR Reference Manual'[8].

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