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Expert System and Assessment of Earthquake Hazard Reduction

Système expert pour la protection des bâtiments contre les séismes

Expertensystem für den Schutz von Mauerwerksbauten gegen Erdbeben

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SUMMARY

This paper describes an expert system applicable to one and two storey buildings, representative of the background and methodology of experienced engineers familiar with the evaluation of existing unreinforced masonry buildings in accordance with the Los Angeles Building Code. Building properties have to be input. Code lateral forces are established and stresses in the main resisting elements including walls, piers, diaphragms, chords and various structural connections are determined. Actual stresses are compared with allowable ones. The expert system has been checked by application to three prototype buildings. Excellent correlation with traditional assessments was obtained.

RÉSUMÉ

Il est ici question d'un système expert applicable aux bâtiments à un et deux étages, capable de transmettre les connaissances et la méthodologie d'ingénieurs expérimentés, pour la vérification des constructions existantes en maçonnerie non armée, et en conformité avec le règlement de sécurité des constructions de Los Angeles. Après avoir entré les caractéristiques de l'ouvrage, ce système détermine les forces horizontales équivalentes à la norme et en déduit les contraintes dans les éléments porteurs principaux, tels que parois, piliers, diaphragmes, membrures et diverses liaisons structurales; les contraintes ainsi calculées sont ensuite comparées aux contraintes admissibles. Ce système expert a été testé en l'appliquant à trois prototypes de bâtiment et il a donné une excellente concordance avec les méthodes de contrôle traditionnelles.

ZUSAMMENFASSUNG

Der Beitrag beschreibt ein Expertensystem für ein- und zweigeschossige Gebäude, das das Hintergrundwissen und die Vorgehensweise erfahrener Ingenieure bei der Ueberprüfung bestehender Bauten aus unbewertem Mauerwerk wiedergibt. Nach Eingabe der Bauwerkseigenschaften werden die horizontalen Ersatzkräfte nach Norm ermittelt un daraus die Spannung in den Haupttragelementen - wie Wänden Preilern, Scheiben, Riegeln und verschiedenen tragenden Verbindungen - berechnet; diesen werden dann die zulässigen Spannungen gegenübergestellt. Bei der Validierung an drei Prorotypgebäuden ergab sich eine hervorragende Uebereinstimmung mit herkömmlichen Untersuchungsmethoden.

1. BACKGROUND

A large proportion of the particularly hazardous buildings in the world are constructed of unreinforced masonry. Many were erected prior to the implementation of building codes calling for specific earthquake resistance provisions. Demolishing and rebuilding the large stock of existing buildings is not generally a viable alternative, hence, much effort is being expended on the task of upgrading, or seismically retrofitting these structures.

Several guidelines have been developed to identify and evaluate the seismic risk of existing buildings but a significant factor in undertaking this task successfully is the experience of those engaged in it. Partially because of the irregular occurrences of damaging earthquakes, only a limited number of building officials can be expected to have had field experience of examining earthquake damage coupled with a thorough understanding of the principles and strategies of seismic retrofit work. This makes the assessment of earthquake hazard reduction a prime candidate for a knowledge-based expert system approach.

In 1981 the city of Los Angeles adopted an ordinance [1] to promote public safety and welfare by reducing the risk of death or injury that may result from the effects of earthquakes on unreinforced masonry buildings constructed before 1934. Past experience had shown that such structures are susceptible to partial or complete collapse during moderate to strong earthquakes. Division 88 of the Los Angeles building code provides systematic procedures and standards for identification and classification of unreinforced masonry bearing wall buildings based on their present use. Priorities, time periods, and standards are specified. The retrofit provisions of the Division are considered to be minimum standards for structural seismic resistance. Although they were established primarily to reduce the risk of life loss or injury, in severe seismic shaking compliance will not necessarily prevent loss of life, injury, or damage to upgraded buildings.

A contract awarded by the National Science Foundation to the Applied Technology Council with the objective of devising a methodology to determine potential earthquake hazards and identify the buildings or building components that present unacceptable risk to human lives resulted in the report [2] ATC 14, "Evaluating the Seismic Resistance of Existing Buildings." This document provides a practical guide to engineers for determining potential earthquake hazards in most types of existing buildings, including unreinforced masonry ones.

Such documents as the Los Angeles Division 88 and the ATC 14 represent agreement amongst groups of experts in the field of building rehabilitation about what the minimum acceptable standards for these buildings should be. The methodology presented can also provide an inspection "format" to be followed when actually inspecting the structures. This "format" ensures that all aspects of seismic rehabilitation established in the code are reviewed and analyzed.

The objective of the work reported in this paper was to develop an "expert system" computer program based on the methodology presented in both of these documents. The program complies essentially with the provisions of Division 88 of the Los Angeles buildings code and follows the basic procedures presented in the ATC report. The format ensures that all aspects of rehabilitation reflected in these documents, including present use, structural configuration and building condition, are reviewed and analyzed. The approach is based on the expert system shell EXSYS. Interface with Lotus 1-2-3 facilitates a spreadsheet approach to data handling. The expert system, containing 265 rules, was developed on a Hyundai Super 286 C IBM-compatible PC equipped with 312k of memory and 80,287 math coprocessor and can be run on any similar configuration.

2. THE EXPERT SYSTEM SHELL PROGRAM EXSYS

2.1 General Information

The commercially available EXSYS [3] shell program was chosen for the project reported. This shell does not contain any rules itself, but is designed to enable the user to create his own expert system by entering rules which will be processed and run by the EXSYS program. The user prompts the computer to help solve the problem by entering IF-THEN-ELSE rules explaining the steps involved in the decision-making process. The rules are a collection of English sentences and mathematical equations which can be easily read by anyone familiar with the problem domain. A rule is made up of a series of IF conditions and list of THEN and ELSE statements reflecting the probability of a particular choice being the appropriate solution to the problem. If the computer determines that all of the IF conditions in a rule are true, it adds the rule's THEN conditions to what it knows to be true. If any of the IF conditions are false, the ELSE conditions are added to what is known. The computer determines what additional information is needed and how best to get the information. If possible, the program will derive information from other rules rather than asking the user for information. This ability to derive information allows the program to combine many small pieces of knowledge to arrive at logical conclusions about complex problems. EXSYS derives information by backward chaining unless commanded to use the forms of forward chaining available in the program. It is written in the C language which is noted for its speed and compactness of code.

2.2 Hardware Used in the EXSYS Development

The computer used for development of the unreinforced masonry seismic hazard reduction expert system was a Hyundai Super-286C IBM compatible personal computer. A Rampage AT expanded memory board with 512k of memory and a 80287 math coprocessor was installed. Microsoft DOS version 3.2 was used.

3. THE EXPERT SYSTEM "URMDV88"

3.1 General Considerations

As unreinforced masonry buildings have been constructed in many different sizes and shapes, it is impractical to create a knowledge base that contains the necessary knowledge to analyze every possible building. Additionally, expert systems become less efficient as the problem they are programmed to solve becomes more broad. Consequently, the expert system reported, URMDV88, has been programmed to analyze buildings with only one or two stories with a square or rectangular floor plan. This specific scope makes it feasible to develop a knowledge base that can effectively analyze a building and meets the restrictions defined by the scope.

The expert system is named URMDV88 in recognition of the fact that the unreinforced masonry buildings are being analyzed in accordance with Division 88 of the Los Angeles Building Code [4], providing engineers with minimum guidelines for analyzing unreinforced masonry buildings to determine what, if any, actions are required of building owners to reduce the risk of death or injury that may result from the effects of earthquakes. These buildings are classified using parameters established in the code. Lateral load coefficients for the building or parts of the building are determined using the building's classification. Allowable loads and dimensions for structural members and components are defined in the code.

URMDV88 is programmed to determine these values specified in the code. The expert system requests information about the building and then derives the allowable values for the building. The system also calculates actual values and compares them to the derived allowable values. The report generator in EXSYS is then used to detail out the results of the analysis.

URMDV88 uses one choice in all of its rules. The choice is only used to ensure that a rule will fire if all of its conditions are verified. Rules will not fire unless the THEN portion of a rule has an established choice. All of the rules in URMDV88 were designed to output information to the report generator if they fire. Therefore, all of the rules must have the choice included in the THEN portion of the rule.

The allowable values are analyzed and defined by the expert system. The system is designed to calculate values for variables and compare these values to the code allowable values. Certainty factors are not used because the calculated loads or dimensions either meet code specifications or they do not. The use of one choice causes EXSYS to analyze the rules in the order that they are written in the knowledge base. Initial rules define the code parameters and the succeeding rules perform the comparisons. The report generator specification is designed to print calculated variable values or notes if a rule fires. The notes are statements of compliance or recommended actions. The variables or notes will be printed in the order that the rules fire. The report generator is used to develop a report that details the results of the calculations and also whether or not the code parameters have been met. The choice is not included in the report. The choice is given the same certainty or probability factor in all of the rules so that the rules will fire in a consistent order. The expert system uses all of the rules in the derivation of information.

3.2 Components of URMDV88

The expert system is contained in two knowledge bases. Blackboarding is used to transfer information from one knowledge base to the other. The first knowledge base is given the name URMDV88a and the second knowledge base is named URMDV88b.

URMDV88a classifies an unreinforced masonry building according to DIVISION 88 of the Los Angeles Building Code. The lateral load factors and allowable loads and dimensions for the building and its components are established in this section of the expert system. Allowable soil pressures are also established and then compared to actual foundation pressures.

LOTUS 1-2-3 is interfaced with URMDV88a in order to receive data pertaining to an existing building's material properties and dimensions of the various structural components. The spreadsheet INDAT.WK1 is used to do this. This spreadsheet is filled out before the expert system is run. The dimensions of the building's structural components are entered into INDAT.WK1. The spreadsheet calculates the weight of the building and its components. The dimensions and weights are saved to a file called VAR.PRN.

URMDV88a is instructed by the system's configuration file to read the data contained in the file VAR.PRN. The configuration file is named URMDV88a.CFG. This file also specifies the file names to be used when passing data between EXSYS and LOTUS. The file PASS.PRN is used to pass data from EXSYS to LOTUS 1-2-3. The file RETURN.PRN is used to pass data from LOTUS 1-2-3 to EXSYS. The configuration file is also used to instruct EXSYS to request the date and building name at the beginning of each run.

The knowledge for the first knowledge base is contained in the files URMDV88a.RUL and URMDV88a.TXT. These files are created by EDITXS when developing the expert system. This knowledge base contains 264 variables and 73 rules. When URMDV88a is run it automatically reads the VAR.PRN file. The system will then ask the user for the date and building name. The user then responds with the information that the system will request concerning the building's occupancy and structural components. This information is used to establish the various lateral load factors and allowable loads specified in the code. The system then calls 1-2-3 after this is accomplished.

The spreadsheet AUTO123.WKl is automatically loaded when 1-2-3 is called. This spreadsheet is used to instruct the user on which spreadsheet to call next. Different spreadsheets are required depending on whether the building is one story or two story. AUTO123.WK1 reads the number of stories from the file LWX.DAT which is generated by the INDAT.WK1 spreadsheet. The user is automatically given instructions on how to call the correct spreadsheet. This is done using the macro capabilities in 1-2-3.

The system will load the spreadsheet ONEST.WK1 if the building is a single story one. The spreadsheet will automatically import the files VI.PRN, VP.PRN, and LWX.PRN from files created by the INDAT.WK1 spreadsheet. The spreadsheet also reads data generated by URMDV88a from the PASS.PRN file. The user will then fill out the highlighted cells in the spreadsheet. The spreadsheet calculates wall shears, diaphragm shears, and pier stresses using the appropriate factors generated by the expert system. The spreadsheet results are sent back to URMDV88a using the RETURN.PRN file.

The system will load the spreadsheet TWOST2.WK1 if the building is a two-story structure. This spreadsheet calculates building story shears and also the wall shears, diaphragm shears, and pier stresses in the top story of the building. In addition to the files listed above for the one-story building, this spreadsheet will automatically import the file V2.PRN from INDAT.WK1. Data is passed to the spreadsheet using the PASS.PRN file. The user fills out the highlighted variables and then follows the instructions that will call the spreadsheet TWOST1.WK1. The calculated shears and stresses are saved to files named TOL1N.PRN and TOL1T.PRN which will be imported by TWOST1.WK1.

TWOST1.WK1 calculates the wall shears, diaphragm shears, and pier stresses in the bottom story of the building. The user fills out the highlighted variables and the calculations are automatically made. The results of both TWOST2.WK1 and TWOST1.WK1 are automatically saved to the RETURN.PRN file which is read by URMDV88a.

The system will return to URMDV88a when the user completes the work in the spreadsheets and quits the 1-2-3 program. URMDV88a will begin at the same point it left when the 1-2-3 program was called. The expert system will then question the user on soil conditions observed at the building site. The report generator file is used to create a file which stores the results of the information derived and calculated in URMDV88a. This data file is named INPUT.DAT. The information included in this file includes the information read from the spreadsheets and URMDV88a.

The second knowledge base is called URMDV88b and is contained in the files URMDV88b.RUL and URMDV88b.TXT. This knowledge base contains 265 rules and 338 variables and compares the actual loads, stresses, and dimensions of various structural components of the building to the allowable values. The URMDV88b.CFG file instructs the system to automatically read the INPUT.DAT file generated by the first knowledge base. There is no user interaction or external programs called in this knowledge base. The results are printed to a file specified by the report generator.

3.3 Directories and Path Names

Path names tell the computer where to find the files and programs required by the expert system. The EXSYS program gives the programmer the option of using different directories to store programs and files.

URMDV88 was developed with both EXSYS and the LOTUS 12-3 program in the same directory. The directory name is EXSYS and it is on the C drive of the computer. All the files used by URMDV88 and the 1-2-3 spreadsheets are also stored in the EXSYS directory.

4. ASPECTS OF URMDV88 EXPERT SYSTEM

4.1 General

Space limitations prevent all the considerations taken into account in the Expert System being described in detail. A representative selection is presented below.

4.2 Building Geometry and Weight

The spreadsheet INDAT.WK1 is used to input the dimensions of the walls, parapets, roof diaphragm, floor diaphragm, and foundation. The roof dead weight, floor dead weight, weight of masonry, and contingency weights are also input into the spreadsheet. The contingency weights are to allow for additional weights that may be applied on the horizontal diaphragms such as partition loads.

The spreadsheet automatically calculates the weight of the building and its components. This calculation is performed by multiplying the weight of the masonry times the volume of each of the building components. The weight of the components are then summed up to determine the total building weight. The weight of the footing is not included in the building weight. The weight of the footing is calculated in the spreadsheet by multiplying the volume of the concrete in the masonry wall footings by 150 lbs. per cubic foot.

URMDV88a approximates the soil bearing pressure created by the lateral loads generated in earthquakes using the flexure formula. The system calculates the moment created by the lateral loads by multiplying the lateral load by the distance from the lateral load to the ground elevation. This moment is calculated in both principal directions of the building.

The second moment of area of the foundation is calculated in both principal directions of the building by the spreadsheet. The second moment of area of the foundation components are summed to calculate the total foundation second moment of area in each direction. Slabs on grade are not included in the footing weight or moment of inertia calculations.

4.3 Building Classification

Section 91.8803 of the Los Angeles Building Code contains the definitions of the types of unreinforced masonry buildings used to determine the building classification. The building type depends primarily upon the occupant load of the building. The procedure for determining the occupant load is specified in Section 91.3301(d) of the Code. The rating classifications are established in Table No. 88-A as described in Section 91.8804 of the code.

The classification of the building is performed in URMDV88a. The user is required to supply the correct values for Qualifiers 1 through 5 as required by the expert system. Rules 1 through 7 contain the knowledge required to classify the structure. The expert system derives the building classification based on these rules.

4.4 Horizontal Force Factor

Section 91.8808(a) of the code specifies the procedure required to establish the minimum total lateral force that acts on the building. The following equation is used to define the force:

$$V = (IKCS)W \tag{1}$$

The weight of the building is represented by the letter W and the horizontal force factor for the building is denoted by the (IKCS) term. The value of (IKCS) need not exceed the values set forth in Table No. 88-D of the code. The horizontal force factors are based on the buildings classification and will be determined by the expert system without user input. Rules 8 through 10 determine the horizontal force factor for the building.

Section 91.8808(b) of the code specifies the minimum lateral force that acts on an element of a building. This force is represented by the following equation:

$$F_p = (IC_pS)W_p \tag{2}$$

The weight of building element is represented by the W_p term. The (IC_pS) term is determined by two tables in the code. Table No. 88-E provides the maximum required value for the product of I and S based on the building classification. The maximum values for C_p are provided in Table No. 88-F.

The expert system determines the value of IS in Rules 8 through 10. The total horizontal force factor for any element of the building is determined by the expert system in Rules 11 through 28. The user is required to supply the values to Qualifiers 7 and 9 to identify the building elements contained in Table No. 88-F which are observed during the building inspection.

4.5 Allowable Shear Stress for Tested Unreinforced Masonry Walls

Section 91.8809(g)1 of the code specifies the procedure used to determine the design seismic in-plane shear stress that is allowed for the unreinforced masonry walls in the building. The design shear stress is substantiated by tests performed as specified in Sections 91.8809(e)3 and 4. The design stress is related to the test results in accordance with Table No. 88-J of the code. Interpolation is allowed in this table.

There are two types of test allowed by the code. The test specified in Section 91.8809(e)3 is the in-place shear test. The test specified in Section 91.8809(e)4 is the core test. These tests have to be performed by testing agencies approved by the building department. The user is required to supply the expert system with the value for Qualifier 10 which identifies the test method used. The system will then request the value for applicable test results from the user. This is either Variable 12 or Variable 14 depending on which test is performed. The value should not include the addition of 10 percent of the axial stress allowed due to the weight of the wall. This increase is included in the spreadsheet portion of the system if it is required.

Rules 29 through 31 determine the design shear stress if the seismic in-place shear test is utilized. Rules 32 through 36 determine the design shear stress if the core test is selected. These sets of rules perform the interpolation allowed by the code.

4.6 Allowable Height: Thickness Ratio of URM Walls

Section 91.8809(b)1 of the code specifies that unreinforced masonry walls analyzed in accordance with Division 88 may provide vertical support for roof or floor construction and also resistance to lateral loads. The bonding of such walls is required to comply with section 91.2412(b)1 of the code.

Section 91.8809(b)1 goes on to specify that tension stresses due to seismic forces normal to the wall may be neglected if the wall does not exceed the height- or length-to-thickness ratios and in-plane shear stresses as set forth in Table No. 88-G of the code. Buildings with crosswalls, as defined by Section 91.8803, have different allowable ratios than buildings without crosswalls. The allowable ratios in the table can only be used if the wall contains the minimum mortar quality required by Section 91.8809(e) and the building has a rating classification II, III, or IV. All walls in Class I buildings are required to be analyzed in accordance with Section 91.8808(f) of the code.

Rules 38 through 41 assign the allowable ratios for one- or two-story buildings that Table No. 88-G can be applied to. Rule 37 is used to instruct the user to analyze the walls for stability in accordance with Section 91.8808(f) if the minimum mortar quality standards are not met. Rule 42 instructs the user to use Section 91.8808(f) if the building is a Class I structure.

4.7 Allowable Shear Values for Horizontal Diaphragms

Section 91.8809(b)2 of the code specifies that existing materials may be used as part of the lateral load-resisting system provided that the stresses in the materials do not exceed the values shown in Table No. 88-H. This identifies various types of horizontal diaphragms and their allowable shear values. The user provides the values for Qualifier 14 to identify the roof diaphragm and Qualifier 15 to identify the floor diaphragm for two story buildings. The expert system then assigns the allowable shear values using Rules 43 through 45 for the roof. Rules 47 through 50 assign the values for the floor diaphragm if the building has two stories.

4.8 Horizontal Diaphragm Supported by URM Walls

Section 91.8810(b)3 of the code specifies that ledges or columns shall be installed to support vertical loads of the roof or floor members where trusses and beams, other than rafters or joists, are supported on masonry. The user is required to supply the values for Qualifiers 18 and 19 which identify the roof and floor support systems, respectively. Rule 46 sends a note to the project report if ledges or columns are required to support the vertical roof loads. Rule 51 sends a note to the project report if ledges or columns are required to support vertical floor loads for two story buildings.

4.9 Interface with LOTUS 1-2-3

Rule 52 calls the 1-2-3 program and loads the AUTO123.WK1 spreadsheet. Qualifier 11 contains the RUN command. The values of variables derived by the expert system that are required to calculate and analyze the in-plane stresses for unreinforced masonry walls is sent to the spreadsheets in the PASS.PRN file.

4.10 In-Plane Stresses for One-Story Building

The spreadsheet ONEST.WK1 is called by URMDV88a to calculate the base shear for the building, wall shears, diaphragm shears, and stresses in wall piers due to in-plane seismic loading. The spreadsheet automatically imports the required data to calculate the base shear, wall shears, and diaphragm shears. The user is required to input the pier dimensions, pier end conditions, and weight the piers are supporting before the pier stresses are calculated.

The base shear is calculated using the formula (1) discussed in section 4.4 above. The base shear is calculated in both principal directions of the building. The total weight of a building that contributes to the seismic loading along one principal axis is usually different from the weight that contributes to the loading along the other principal axis. The lateral load is assumed to be resisted by the shear walls that are parallel to the direction of loading. These walls feel the weight from the parapets, roof diaphragm, one half of the walls that run perpendicular to the load, and themselves. The force in the walls that run perpendicular to the direction of the load is resisted at the diaphragm level and at the ground level. The diaphragm transmits the shear generated by the weight of the upper half of the perpendicular walls to the walls parallel to the load. The same horizontal force factor is used in both directions.

The spreadsheet assumes a flexible diaphragm and the base shear is distributed to the walls by the tributary area supported by each wall. The diaphragm shear at each wall is also calculated. This calculation is made by dividing the wall shear by the total length of the wall. This assumes that the wall has a continuous chord which connects all the piers.

The seismic wall shears are distributed to the piers by the relative rigidities of the piers. The calculations performed in the spreadsheet assume that the piers are parallel to each other. The user can select either a fixed end condition or cantilever end condition for each pier. The cantilevered condition is the default condition. The shear stress in a pier is calculated by dividing the shear carried in the pier by the cross sectional area of the pier.

Section 91.8809(g)2 of the code specifies that compressive stresses in unreinforced masonry walls that have a minimum design shear value of 3 psi shall not exceed 100 psi and that design tension stresses for these walls are not allowed.

The spreadsheet calculates the axial stress in each pier by dividing the weight supported by each pier by its cross sectional area. Automatic calculation of the supported weight is undertaken by assuming that the pier supports that portion of the wall and the parapets proportional to the length of the pier.

The spreadsheet calculates the bending stress in each pier created by the seismic shear using the flexure formula. The moment created in each pier is calculated by multiplying the pier shear by the height of the pier for piers that have a depth that is at least 80 percent of the length of the wall. The moment arm is taken as one half the height of the pier for piers whose depth is less than 80 percent the length of the wall. The bending stress is calculated by dividing the moment in the pier by the section modulus of the cross section of the pier. Tensile stresses are denoted as positive stresses.

The spreadsheet calculates the maximum compressive stress in each pier by summing the axial stress and the bending compressive stress. The maximum tensile stress is calculated by summing the axial stress and the bending tensile stress.

The code states that the allowable shear stress in unreinforced masonry walls may be increased by the addition of 10 percent of the axial stress due to the weight of the wall directly above the pier in consideration. The spreadsheet allows the user to take this increase if the actual calculated pier stress is greater than the allowable shear stress taken from Table No. 88-J. This is done by entering the dimension from the top of the parapet to the pier. The spreadsheet will then automatically calculate the allowable stress increase that can be taken for the pier and add it to the allowable stress.

The spreadsheet compares the actual shear stresses in each pier with the allowable stresses. The message "OK" will be displayed if the pier is not overstressed. The message "IN-PLANE SHEAR EXCEEDED" will be displayed if the calculated shear stress exceeds the allowable shear stress. The spreadsheet will send a flag to the expert system that indicates whether or not the allowable shear stress is exceeded in any pier for each wall. The spreadsheet sends the maximum compressive stress and tensile stress for each wall to the expert system for comparison to the allowable stress values.

4.11 Other Considerations

Further portions of the expert system cover such aspects as the in-plane stresses for two-story buildings, soil bearing pressures, parapet stabilization, wall tension anchors, diaphragm shear comparison, diaphragm shear bolt spacing, wall stability analysis for out-of-plane seismic loading, chord force analysis, analysis of in-plane shear stress, and analysis of tensile and compressive stress generated by in-plane loading. These additional aspects call upon more than 200 separate rules to achieve the appropriate analyses.

5. VERIFICATION OF THE EXPERT SYSTEM

5.1 The Test Cases

Validation of the expert system was undertaken by applying it to the analysis of three buildings in the Los Angeles area which had been subjected to seismic retrofit. Two of the buildings are of one-story, the third has two stories. The first building is a Class I structure whereas both the others are Class III.

The first building has two shear walls resisting the lateral loads in each of the two principal footprint axes. The second building has three shear walls in one direction and two in the orthogonal axis. The third has two shear walls on each principal axis and both a floor and a roof diaphragm.

Aspects investigated included parapet stabilization, wall tension anchor provision, diaphragm shear bolt provision, wall stability, chord forces, in-plane shear, and tensile and compressive stresses.

Excellent agreement was obtained between the actual deficiencies identified and remedial measures prescribed by the engineer and those derived using the expert system in all but three instances.

In the first of these, the expert system concluded that one wall was stable in the second test-case building, whereas the engineer judged it to be unstable. The explanation for the discrepancy is that whereas the expert system used the average height of the wall, the engineer was aware that the height varied and the taller section was less stable. The expert system user could avoid the mismatch by feeding in the maximum height of the wall as the average height, however, this would tend to give rise to an over-conservative retrofit solution. Since the report generated by the expert system lists the maximum allowable height for each wall, it is convenient to review the system's recommendations and to fine-tune as necessary.

The second and third areas of disagreement involved the in-plane shear and tensile stresses for one pier in the third test case. The expert system prescribed reinforcement for both load cases at this pier, whereas the engineer chose to use his judgement to determine that the building's new roof diaphragm would be lighter than the original one, resulting in smaller values of pier stresses. The allowable stresses were within two percent of the actual shear calculated using the heavier roof which the engineer judged to be acceptable, whereas the expert system does not have the ability to exercise such discretion.

6. CONCLUSION

On the basis of the limited testing undertaken, the expert system is judged to be functioning as intended and provides the basis of a satisfactory solution to the objective undertaken.

7. ACKNOWLEDGEMENT

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