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Earthquake Construction
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Earthquake Design for an Eight-Story Apartment House

Building in San Francisco designed to carry a seismic force of 1 per cent in frame and 4 per cent in walls—Additional cost is less than capitalized saving on insurance policies

By Harold B. Hammill
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DEFINITE figures from comparative bids on two alternate designs for an eight-story apartment building in San Francisco showed that the provision for a 4 per cent earthquake force increased the cost of the structure 1.9 per cent over a design for vertical loads only. When the capitalized cost of earthquake insurance plus the cost of the higher fire insurance for the alternate design was considered, the cost of the earthquake-resistant design was actually less. The design was prepared in anticipation of the adoption of a proposed earthquake ordinance by San Francisco, which had been prepared and was under consideration by the board of supervisors at the time this design was made.

Earthquake code

For a number of years the engineers and architects of California have realized that many city building ordinances lacked important provisions regulating building design. It was not until 1925 that a movement was started to improve building conditions; this developed into the study and preparation of a state uniform building code under the sponsorship of the California State Chamber of Commerce. The organization compiling this code consisted of committees both in southern California and in northern California representing the American Society of Civil Engineers, the American Institute of Architects, the Pacific Coast Building Officials Conference and the Associated General Contractors of America.

In the development of a proper uniform building code for this state, it was realized that it was extremely important to include provisions requiring definite resistance to earthquake forces. A limited amount of research information on the subject was available, certain experiments on models of buildings having been conducted on the "shaking table" at Stanford University. Using this information, but relying principally on the judgment of those engineers who are members of the code committee of the American Society of Civil Engineers, a chapter was drafted covering minimum requirements for earthquake resistance.

Because of the economic situation it was impractical for the state chamber of commerce to continue its support, and the work of compiling the building code was discontinued. Local engineers realized San Francisco's particular need for an earthquake ordinance and urged that the proper provisions be incorporated in the city's present building code. The earthquake chapter as written by the building code committee was submitted to the members of the Structural Engineers Association of Northern California for criticism and suggestions. Certain provisions were modified to conform to suggestions made by members of this association, and the proposed ordinance was then submitted to the board of supervisors of San Francisco for adoption.

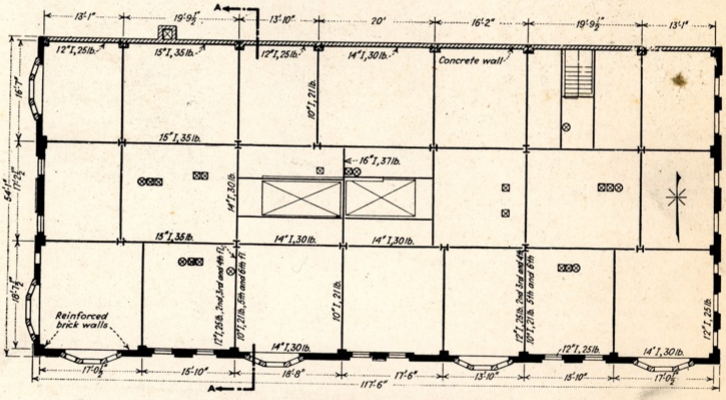


Fig. 1—Typical floor framing, showing the successful lining up of interior columns and the extent of reinforced brick walls. Section A-A is the one analyzed in the moment diagram, Fig. 2.

Preliminary work in the development of the ordinance involved an extended study in the practical methods of handling the detailed design of building frames for horizontal forces. John B. Leonard, chairman of the local engineering code committee and superintendent of building inspection for the city of San Francisco, delegated the working out of this problem to S. M. Cotten, in his office. After months of study Mr. Cotten developed a method based fundamentally on the principle of slope deflection that is very clear and easy to apply; this method was used in determining the moments in the structural elements of the design of the apartment house here described.

Subsequent to the preparation of the

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ordinance the earthquake at Long Beach focused public opinion on the need for earthquake-resistant design. As a result, state legislation was enacted *(ENR,* June 1, 1933, p. 722) requiring all buildings in California to be designed for definite horizontal forces. Some provisions of the proposed city ordinance were in conflict with the state legislation. The ordinance has now been amended to agree and is before the supervisors for adoption. Among the various provisions of the original ordinance, which was the basis of the present design, was the requirement that a building founded on a soil capable of withstanding a pressure of 4 tons per sq.ft. should be designed to resist a horizontal force of 4 per cent of its weight. If a flexible story were incorporated in the design, a reduction in the 4 per cent factor would be permitted.

In determining the structural sections required to resist earthquake forces, the unit working stress for the materials could be increased 100 per cent for all members except columns, which were limited to an increase of 75 per cent. The ordinance further provided that the structural frame should be designed to resist either 1 per cent of the weight of the building or 15-lb. wind pressure, whichever is the greater, with an increase in working stress of 33⅓ per cent. One clause in the ordinance provided that any connection that is restrained must be proportioned to resist the stresses due to moments from vertical loads as well as from horizontal loads.

Shortly after the ordinance was presented for adoption to the board of supervisors, the writer was retained to prepare the structural design of an apartment house to be built at 25th and Bartlett Sts., San Francisco. On the supposition that the proposed ordinance might be adopted before the plans for this building could be completed, it was decided to design it in accordance with these earthquake provisions.

The building is 54x117½ ft. and was originally planned for six floors and one garage, but before the plans were completed a mezzanine floor was added to provide additional garage space. The structural elements consist of a steel frame with 2½-in. concrete slabs supported on junior beams for the apartment floors and reinforced-concrete construction for the garage floors. The first-story walls and the entire rear wall are of concrete. The front and two side walls above the first story are of reinforced brick.

With the cooperation of the architect a very satisfactory arrangement of the structural members was obtained (Fig. 1). All the columns are lined up to form complete longitudinal bents. In a transverse direction there are four complete bents in which all the transverse horizontal forces are concentrated. Of the 32 columns, 16 are turned with webs north and south and 16 with webs east and west. Due to practical difficulties, all connections of beams to column webs are designed to transmit shear only. Only the connections of beams to column flanges are designed to develop moments. The 2½-in. concrete floor slabs are designed to act as horizontal girders to transmit horizontal forces to the resisting bents and to the walls. The structural-steel frame is designed to carry 1 per cent of the weight of the building as a horizontal force.

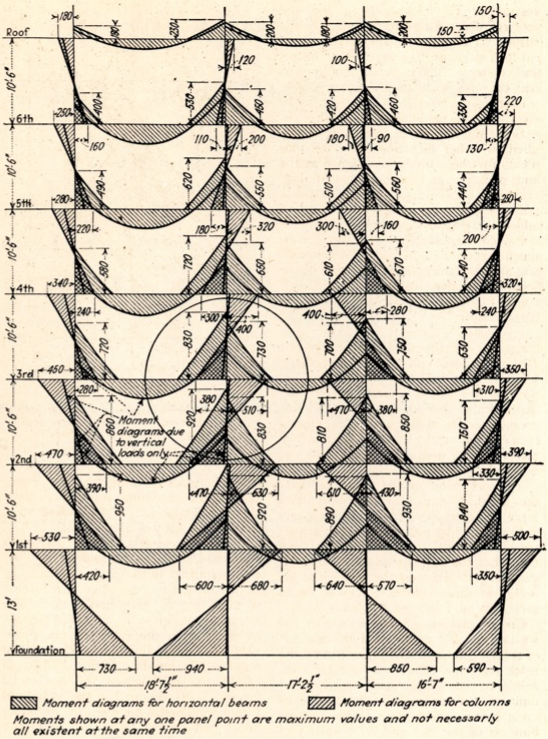


Fig. 2—Moment diagram of a transverse frame (section A-A, Fig. 1) showing maximum summation of moments for beams and columns. The detail moments of a typical beam-column connection (in circle above) are shown in Fig. 3.

The moment diagrams for a typical transverse structural-steel bent that carries its proportion of the earthquake forces in the north and south directions is shown in Fig. 2. These moment diagrams for both horizontal and vertical loads are shown for a building consisting of six stories and one garage floor, the structure for which the complete analysis of the frame was made. After the addition of a mezzanine floor to the design, the moment values were modified without making another complete frame analysis. All cost figures are for the structure as finally designed and constructed.

Referring to the moment diagram and the detail (Figs. 2 and 3), the webs of the columns in the transverse frame are in the plane of the frame, and since all beams connect to column flanges, they are restrained at both ends. The end moments of all beams were determined for vertical loads on the basis of complete end restraint. A study was made for the angular rotation occurring at the end of a typical beam, from which information a percentage factor was obtained for reduction of all end moments that had been computed for complete

restraint. The closing lines for the moment diagrams were accordingly adjusted. The diagram shows the vertical-load moment diagrams for all beams and columns. The moments in all beams and columns were then determined for a lateral load equal to 1 per cent of the weight of the building.

Since the horizontal force may be applied in either direction, only the moments for these forces are shown at the ends of beams and columns that produce critical values—i.e., only those moments that are of the same sign and therefore added to vertical load moments. Since the negative moments in beams are so much larger than the positive moments and are the values that fix the size of the sections, the moment diagrams for horizontal forces are shown only above the datum lines.

All beams with ends restrained were connected to column flanges with split I-beam connections. The web of the I-beam connector was left as long as possible to serve as a coverplate for the main beam, thereby producing an increased section at the point of maximum moment. In many cases 1-in.-diameter rivets were used for connection of I-beam connectors to columns.

The provision of the ordinance that the building must carry a horizontal force of 4 per cent of the weight is met in this design by providing proper resistance in the walls, which are far more rigid than the elements of the structural steel frame. To meet the stresses as allowed in this ordinance, it was found necessary to reinforce the brick walls.

Critical stresses existed in the east and west walls and determined the amount of reinforcing steel that is used in all the brick masonry. Computations for steel reinforcement were based on the formulas for shear reinforcement of concrete beams. The shear in the critical buttress of the east and west walls was 56 lb. per sq.in. The ordinance provided that the maximum allowable shearing stress in plain brick masonry for dead and live load should not exceed 20 lb. per sq.in. for mortar as used on this job. A 100 per cent increase for earthquake forces brought the allowable value up to 40 lb. per sq.in.

Since reinforcement was required, an amount has been provided conforming to the minimum requirements of reinforced-concrete construction. All bars are round and are placed in the mortar joints in the center of the 8-in. wall. Two vertical bars, one ½ in. and one ⅝ in. are placed each side of all openings. Two ⅝-in. horizontal bars are placed at top and bottom of all the openings. In all vertical buttresses ⅝-in. bars at 8-in. centers are placed horizontally between spandrel sections. Vertical bars in the spandrel sections are ⅝ in., with a maximum spacing of 24 in. All vertical bars are guided and are anchored to the frame by passing through holes in the flanges of the spandrel beams. Vertical bars close to columns are tied to them with ¼-in. rods at 12-in. spacing. There are six tons of reinforcing steel in these brick walls, which is equivalent to 1 lb per sq.ft. of net area of wall

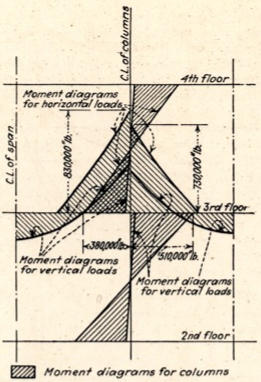


Fig. 3—Moment diagram at a typical panel point, showing the analysis of the total moments for both beam and column.

Before the design, as described, was completed, a local steel fabricating shop was permitted to make an alternate design based on the use of certain foreign sections that this shop had in stock. The alternate design was prepared in accordance with the existing San Francisco building ordinance, which does not require any building under 102 ft. in height to be designed for horizontal forces. This design for the structural frame was based on the use of timber floors and timber joists and of course made no provision for resistance to horizontal forces.

Since both plans were submitted to all contractors bidding on the job, comparative cost data are available. The low bid for the structure providing resistance to horizontal forces was $150,000, or $14,200 more than that for a structure with the timber floor system as designed by the local steel shop. The amount of $14,200 represents the difference in cost of the steel frames plus the difference in cost of the floor systems, one being concrete and the other timber. The cost of the earthquake-resistant structural frame as designed by the writer was:

212 tons of structural frame	$17,413
Junior beams	6,317
	$23,730

Some time after the bids had been accepted, the local steel shop presented a figure of $20,890 to the owner as the cost of furnishing the structural frame, designed by them, plus the junior beams. The extra cost in the structural frame for the earthquake-resistant provisions of the ordinance, therefore, amounts to only $2,840, which is 1.9 per cent of the cost of the building. The owner decided to build a structure that would possess resistance to earthquake forces and accordingly finds that it is not necessary to carry earthquake insurance. For this reason, he does not intend to carry any.

Earthquake insurance would have been considered necessary if the building had been constructed in accordance with the provisions of the present San Francisco building code. The annual cost of earthquake insurance would have been at least $880 per year. There is an annual saving in fire insurance premiums amounting to $166 resulting from the use of concrete floors instead of timber floors. The total annual saving is at least $1,046. This amount capitalized at 6 per cent gives a sum of $17,400, or $3,200 more than the difference in the cost of the two complete structures, and represents a saving of 2.1 per cent.

F. W. Hanchett is the owner of the apartment house. William Clement Ambrose was the architect, and Atkins and Parker prepared the mechanical and electrical design. G. W. P. Jensen was the general contractor.

Author's Comments

Several criticisms and requests for additional information regarding this article were received after its publication. Lack of time and space had prevented the development of the information requested. This opportunity to clarify two points brought out in letters to the writer is appreciated.

A question regarding the distribution of horizontal forces to resisting elements can be explained best by reference to the transverse bents. The four transverse bents that are designed to resist the total transverse horizontal force on the structural frame are alike in all structural sections and therefore are equal in rigidities. In the analysis for the frame only to carry the one per cent horizontal force the relatively very rigid concrete floor slabs transmit equal loads to all bents. Accordingly each bent is analyzed for one-quarter of the total horizontal force. Considering the case of the building carrying the four per cent horizontal force, the relative rigidities of the steel bents and the end walls were determined. The end walls are many times more rigid than the steel bents. The concrete floors acting as horizontal diaphragms are so rigid that they easily transmit

practically the total horizontal force to the end walls and therefore the end walls have been designed to carry the entire four per cent force.

One communication received by the writer of the article criticized the following statement: "The owner decided to build a structure that would possess resistance to earthquake force and accordingly finds that it is not necessary to carry earthquake insurance." This critic commented that it seemed justifiable to make a similar statement regarding fire insurance since concrete floors were constructed instead of timber floors.

At the time the article was written the development of a background for the statement quoted was considered, but it was felt that space limitation in the "Engineering News Record" would not permit this. Without going into too much detail here, it should be stated that the situation in San Francisco several years ago was such that the agencies lending money on building construction demanded earthquake insurance. This insurance carried high premiums and was written with a fifteen per cent deductible provision; that is, the owner must stand all damage up and equal to fifteen per cent of the cost of the building.

Shortly after work was commenced in San Francisco on the development of a new building code, to be uniform for the entire State, the agencies lending money on construction indicated that when structures were built in accordance with the provisions of earthquake resistant construction agreed to by the majority of local structural engineers, they would not demand earthquake insurance to cover loans on such construction.

The fact that the owner of this apartment house could obtain his money without the obligation of taking out earthquake insurance, and the fact that earthquake insurance policies carried the fifteen per cent deductible provision, constitute the reasons for his decision and for the statement that is quoted. The question of carrying fire insurance was distinctly different, and such insurance does not carry a fifteen per cent deductible provision.

Editor's Note:

HAROLD B. HAMMILL graduated from the College of Civil Engineering, University of California, in 1912. He worked for a number of years in the following capacities: Several years as structural designer on various types of hydraulic structures for the Pacific Gas and Electric Company; detailer for the American Bridge Company; designer of derricks and cranes for Edward F. Terry Manufacturing Company of New York; designer of hydraulic structures for the Electric Bond and Share Company of New York City; Naval Reserve, Bureau of Yards and Docks during the World War. In 1920 he entered the employ of Jno. B. Leonard, consulting structural engineer, as designer of bridges, buildings and other structures, and three years later became associated with him in consulting practice.

Since 1927, when Jno. B. Leonard gave up his office to become Superintendent of Building Construction for the City of San Francisco, Harold B. Hammill has conducted his own private practice as consulting structural engineer and has engaged in the design of bridges, buildings, and miscellaneous structures. He has been continuously active in the work of developing a uniform Building Code for the State of California since the code's inception in 1925.

BRICK ENGINEERS' DIGEST

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The first few issues will be devoted to the subject of Reinforced Brick Masonry. The series will, however, cover architectural design and construction features, thus catering to the interests of all parts of the construction industry.

Comments giving additional information on the subject treated will be reprinted.

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