CRITERIA FOR STRUCTURAL DESIGN IN CALIFORNIA SCHOOLS

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Introduction

Any discussion of the criteria of schoolhouse design and construction in California must begin by going back to the Long Beach earthquake and the start of the Field Act (1) itself, to understand the reasons for the severe penalties and other requirements in case of violations.

At that time public attention was focused on the shoddy construction of buildings in general and of school buildings in particular. Many were concerned about the dangers of sending children into inadequately constructed school buildings. Their attention was directed to the responsibilities of the State in this connection, since school attendance is required by law.

The resulting legislation, requiring earthquake resistant construction, was passed shortly thereafter. It has been well described by Mr. Bolin (2); therefore, only an outline will be given here. Briefly, it requires that the Division of Architecture under the police power of the State shall supervise the construction of any school building or, if the estimated cost exceeds $4,000, the reconstruction or alteration of or addition to any school building, for the protection of life and property. It provides for the approval of plans by the Division of Architecture, sets up a fee schedule, provides for rules and regulations by the Division of Architecture to carry out the provisions of the act, and establishes felony penalties for violations. It requires that plans and specifications must be prepared and the work of construction supervised by an architect or structural engineer; but most important of all it requires adequate inspection of the work.

The act applies to all buildings used or designed to be used for elementary or secondary schools or junior college purposes and constructed, reconstructed, altered or added to, by the State or by any city or county, or by any political sub-division, or by any school district of any kind within the State, or by the United States Government, or any agency thereof. It does not apply to private schools, state colleges or to the universities.

Comparison With Other Codes

By requiring professional design and supervision of construction, competent, adequate and continuous inspection of the work during construction, and enforcement of its requirements on a professional level, all in addition to the unusually severe penalties, the act differs from the normal building ordinance. This difference is proper considering the special category of building affected.

All new construction is subject to the provisions of the act. Existing buildings are not affected unless additions or alteration projects costing more than $4,000 are initiated. As the act operates, existing buildings

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may be used throughout their normal service life without conforming, but the life of these buildings cannot be unduly prolonged by modernization nor a structural monstrosity perpetuated unless they are strengthened to provide the contemplated level of safety. However, alteration projects if entirely non-structural and not affecting the safety of the building can be made without strengthening the entire building. Here again it differs from the normal building ordinance in setting the comparatively low dollar value for permitted alterations without full compliance with the code, rather than the 50% of valuation commonly used.

Title 21

The California School Earthquake Safety Law grants the authority to make rules and regulations as necessary to carry out its provisions and although there was little time between the earthquake, the passage of the act, and its effective date, the engineering and architectural professions were not entirely unprepared. Considerable thinking had been done along the lines of earthquake resistance as a result of the Japanese earthquake and the Santa Barbara earthquake of 1925. A code incorporating much of this thinking had been prepared under the sponsorship of the California State Chamber of Commerce. The original rules and regulations of the Division of Architecture, together with the building code known then as Appendix A, were in large part based on this State Chamber of Commerce Code. These rules and regulations have been modernized from time to time to include new materials and techniques and to take advantage of experience gained since 1933 and are known as Title 21.

The format of Title 21 is similar to other building codes in that the first group of requirements are general, covering authority, scope, and the procedure for applying for and obtaining the "written approval" which corresponds to a building permit. Also included are the general requirements for job plans and specifications, and for tests and inspection. It outlines the duties of the school board as the owner, the architect, the engineer, the inspector, and the testing laboratories, and the requirements for reporting and certifying to the construction.

Electrical, plumbing and fire and panic matters are covered by reference to the National Electric Code, the Uniform Plumbing Code, and to the State Fire Marshal's Rules and Regulations (3). The State Fire Marshal in turn refers to the Uniform Building Code (4) for basic building design and construction standards insofar as they affect height, occupancy, fire resistiveness, means of egress, adequacy of exits and the installation and maintenance of fixed fire extinguishing systems. The necessity for fire and panic regulation in connection with the Field Act stems from an Attorney General's Opinion (5) which advises that there are certain responsibilities in requiring the maintenance of reasonable standards of safety and egress from fires likely to result from an earthquake.

Structural Design, Materials and Details

The next group of the regulations in Title 21 are concerned with structural design, materials and details of construction. In general they require a method of design which will admit of a rational analysis and which is in accordance with established principles of mechanics and of structural design. It is not the intention to limit the ingenuity of the designer nor to interfere with existing building rules and regulations, where such rules and regulations are more stringent. New and alternate materials and types of construction must be dependent on rational structural analysis or upon tests establishing physical characteristics and demonstrating adequacy for the intended use. In this case substantiating data must be presented by the architect or structural engineer. The presentation must include details of the proposed construction and if necessary the results of tests conducted by disinterested parties, together with the structural analysis and the recommendations of the architect or structural engineer.

Allowable design stresses for the most common types of building materials are either covered by referring to national standards or are tabulated. With few exceptions they conform to commonly accepted standards. A thirty-three and one-third percent increase in working stresses for members carrying stresses due to wind or earthquake forces is allowed. This increase also applies to wind and earthquake forces when combined with dead and live loads, provided the section is not less than that required for dead and live loads alone.

Deflections

The trend in recent years has been toward lighter and more open structures; also the emphasis is on tighter design, for reasons of economy; and the use of fenestration, for architectural reasons has increased. Therefore it has been necessary to emphasize flexibility more than is common in other codes.

The usual deflection requirement provides that consideration must be given to secondary stresses induced by deflection of the structure or parts thereof when such deflections might create unsafe conditions. In addition, as an interim arrangement until more information becomes available, it has been necessary to restrict the deflection of vertical resisting elements due to wind or seismic load in the plane of the wall to not more than 1/16 inch per foot of height between head and sill of any opening in the wall. It is intended that the deflection of bracing systems, including any inelastic deflections in the connections, should be such that other portions of the structures are not overstressed. These restrictions are established for the purpose of minimizing glass and plaster breakage and possible hazards to the occupants therefrom. They also serve to reduce property damage.

For similar reasons and to reduce excessive accumulation of both elastic and inelastic deformations, arbitrary limits for the spacing of resisting elements have been found necessary. They apply to buildings having horizontal wood diaphragms or rod bracing systems which if having continuous steel or concrete framing systems or continuous masonry walls must have vertical resisting elements, parallel to the length of the building, in each resisting plane for each 105 feet of building length. Under the same conditions in buildings of wood construction the limit is 80 feet. In both cases an element in each resisting plane must be within 40 feet from each end of the building. Recent proposals, if adopted, will increase these limits to 125 feet and 100 feet respectively with the 40 feet limit, from end of building eliminated. In the transverse direction shear resisting elements normal to the longitudinal walls must be provided at such spacing that the ratio for floor or roof diaphragms shown in Table 116 is not exceeded. Rotation to such an extent as might occur in a three wall building is permitted only in buildings of wood construction. In this case the maximum spacing of transverse resisting elements is one and one-half times the width of a conventionally sheathed diaphragm or two times the width of a special diagonally sheathed or plywood diaphragm.

Design Loads

The live loads used in school design are not significantly different from those required by other codes for other types of construction. The roof live load is an arbitrary requirement varying from 12 lbs. per square foot for large arch or dome roofs or large, high-rise, pitched roofs to 20 lbs. per square foot for small flat roofs. Of course, roofs and skylights which will be subjected to snow loads must be designed for such additional loads as may be proper. The area reduction factors for live loads used in the design of columns, piers, walls, etc., are similar to other codes.

Design and construction for resistance to the horizontal forces due to wind and earthquake are required for every building and every portion thereof, but wind and earthquake forces need not be combined. Moment connections are required to be designed for moments and shears resulting from both vertical loads and horizontal forces. In computing the effect of wind or seismic loads in combination with vertical loads, all vertical loads except roof live loads are considered. In calculating the maximum tensile stresses due to wind forces the direct dead load compression due to gravity may be deducted. However, because of the effect of possible vertical acceleration when considering seismic forces, the maximum tensile stresses may be reduced by not more than 75% of the direct stress due to vertical dead loads.

The wind pressure is assumed to act inwardly or outwardly, in any direction, upon the projection of the building on a vertical plane normal to the assumed direction of the wind. The minimum wind pressure is 15 lbs. per square foot on every portion of the structure not more than 60 ft. above the average level of the ground and 20 lbs. per square foot on every portion above 60 ft.

Seismic Force

The static form (F=CW) for the seismic force formula has been used since the beginning of schoolhouse design regulation in California. Prior to 1952 the value of the coefficient "C" was 10%, applied to the sum of dead and partially reduced live loads for the normal condition, although it could be varied for particular foundation conditions. At that time, in the interest of uniformity with other codes, it was revised so as to vary inversely with the height of the building and to apply in general to dead load only. This change is not particularly significant, however, since the great majority of school buildings are but one story and very rarely exceed two stories in height. The value of "C" for a one story building considered as a whole is 13.3% and it is applied to the total dead load, under seismic action, tributary to the element under consideration. However, in warehouses one-half of live load is included with the dead load. In tanks the entire live load is included. Machinery and other fixed loads are considered as part of dead load. One-half of the portion of snow load which exceeds 20 lbs. per square foot is also included with the dead load.

The value of "C" for special structures or for portions of the building are listed in Table 305. They apply to the anchorage for such structures or portions of the building; however, the building as a whole need only be designed to resist a lateral force based on the coefficient applicable to the building. The horizontal shear at any level is distributed to the various resisting elements at that level in proportion to their rigidities, giving due consideration to the distortion of the horizontal distributing elements. Proper provision must be made for torsional moments when they exist. All permanent structural elements capable of providing resistance are assumed to act integrally with structural frames in resisting the shears and moments due to the horizontal forces, unless they are specifically designed and constructed to act independently. Even in the low buildings common to schoolhouse design, because of the trend toward tighter designs and increased fenestration, there is need for re-evaluating seismic loadings.

The type of building available for study following the Long Beach and Santa Barbara earthquakes, and which greatly influenced the thinking of the engineering profession, was a building having large wall areas, comparatively small windows and a large reserve of uncalculated stiffness and strength. The building of today, on the other hand, contains large glass areas with a correspondingly very small reserve of uncalculated stiffness. The strengths are being calculated down to the last decimal. We are now dealing with an entirely different kind of a building.

In computing strengths there is a factor of safety applied to the ultimate strength of the material. It may vary, but nevertheless it is there and serves to hide any inaccuracies in the assumed loadings. An actual response in the structure of twice that represented by the coefficient "C" would probably do no harm to the structural frame itself. In calculating deflections, on the other hand, the conclusions are purported to be actual values and depend entirely on the assumed loads. There is no direct comparison between strength calculations and stiffness calculations. It is not intended to discount the importance of strength considerations since they obviously are the critical factor in a severe earthquake; yet the economy of design is somewhat out of balance since in less severe earthquakes, property damage resulting from falling plaster, displaced fixtures and other damage to finish might be the main consideration.

One obvious approach to this problem is to so restrict deflections that the overall design is consistent. This approach is impractical since the restrictions tend to be so ridiculous as to be uninforceable and the resulting compromise is unsatisfactory. The "compromise solution" is being tried in the case of mullion deflections and arbitrary spacing of shear elements mentioned previously. Perhaps a different and more realistic approach is needed, ie., a larger force, equated to the ultimate strength of the materials and used for both deflection and strength. The increasing interest in the accuracy of seismic loading as evidenced by the number of articles being published recently is encouraging.

Masonry

Unit masonry construction procedure as practiced in California prior to the earthquake at Long Beach in 1933 was found to be entirely inadequate to prevent collapse of masonry walls when subjected to earthquake stresses. It was necessary for the unit masonry industry to revolutionize not only the design of structural elements, such as walls, piers and beams, but also the art of construction. It was necessary to discard the former methods and techniques employed by artisians and to establish new techniques based on trial and laboratory tests. In addition it has been found necessary to reinforce such masonry much in the same way that concrete is reinforced. At the present time many school buildings are being constructed of reinforced grouted unit masonry. In spite of the many tests and intense study to establish reinforced grouted unit masonry as an important material in the construction industry, the Kern County earthquake in 1952 revealed that this type of construction was not immune to damage.

All masonry used in buildings must be reinforced. Only reinforced grouted brick or filled cell masonry, of hollow clay tile or concrete tile or blocks, may be used in exterior, bearing, or shear walls. It is limited in use to walls, chimneys, lintels and wall beams, columns and piers and cannot be used in combination with other materials of dissmilar characteristics for rigid frames. In brick masonry construction as now used, all reinforcement is embedded in the grout. The minimum thickness for grout spaces containing reinforcement is 2-1/2 inches. Minimum clearance between masonry units and the steel is 1/2 inch.

The use of brick masonry to resist flexure is limited to columns and walls and to wall beams. No column can have a dimension less than 12 inches nor an unsupported length greater than 16 times its least dimension. Column reinforcement must not be less than 0.0075 gross area, nor more than 0.02 gross area. Not less than four bars shall be used. The maximum unit stresses due to direct loads alone, on the gross area, or in combination with loads causing bending, cannot exceed the allowable values for axial compression. Bearing walls cannot be more than 35 feet in height above grade. The axial compressive strength in bearing cannot exceed 270 lbs. per square inch nor

$$270\left[\frac{31}{\frac{h}{t}+14.4}-0.52\right]$$

The thickness of solid masonry exterior walls, interior bearing wall or shear walls must be at least 1/20 the distance between supports. The total area of reinforcement cannot be less than .003 times the sectional area of the wall and neither the horizontal nor the vertical reinforcement can be less than 1/3 the total. Bars must be spaced not more than 24 inches center to center. Anchorage of walls to floor or roof framing must be capable of resisting all applied loads with a minimum of 200 lbs. per lineal foot.

The requirements for interior non-bearing masonry walls or partitions are similar except that intermittently filled cells may be used. In this case the required reinforcement may be concentrated at the floor and roof levels and above and below openings if the interval does not exceed four feet. Also, wire mesh embedded in plaster may be used to resist tensile stresses in brick or hollow unit partitions. The minimum ratio of thickness to the distance between wall or partition supports is 1/24 for brick and hollow units and 1/30 for filled cell construction with a minimum thickness of eight inches.

The standards for reinforced masonry have been covered in some detail because this type of construction is not so well standardized as is the case for other materials. Only the bare essentials have been covered however. Detailed requirements are set forth in Title 21 and other publications. Assurance must be provided that the construction procedures will produce better than average masonry and that there will be expert inspection to achieve this end. Techniques of construction and inspection are covered in various bulletins (6) (7).

Gypsum

Reinforced poured gypsum concrete is at present being used only for roof decking. Allowable working stresses have been set up in Title 21 including use as a roof diaphragm to resist earthquake forces.

Compressive strengths (f_g') of 1000 psi and 500 psi are recognized. The working stresses in percentages of the compressive strength are:

Compression - flexural	25%	Bond - reinforcement anchored	2%
Compression - bearing	20%	Bond - painted steel	1%
Shear - reinforcement anchored	2%		

Electrically welded mesh reinforcement is considered to meet the bond requirements. The minimum reinforcement in slabs used as diaphragms is one-tenth of one percent in each direction. The minimum thickness of poured gypsum slabs is 2-1/2 inches. Bolts, dowels or lugs are required for transfer of shears along the edges of diaphragms.

Wood

The requirements for design in wood follow the national standards (8) with few exceptions. Among these is a requirement for the unstayed length of compression edge of beams, which cannot exceed 50 times the breadth and which, if exceeding 25, must be reduced in stress in accordance with the formula $f = f'\left[1.50 - \frac{L}{50b}\right]$. Also, the common nail values may be increased about 25%. Values of one-half the common nail values are allowed for casing nails. The values for connectors, are eleven-twelfths of the tabulated values in the referenced standard. Stud bearing walls or partitions cannot be used in buildings more than two stories in height. The maximum allowable height is 14 feet clear for 2" x 4" studding and 20 feet clear for 2" x 6" studding. Only grade marked lumber qualifies for full stress values; otherwise 75% of tabulated values are used.

Conventional diagonally sheathed wood diaphragms may be used to resist shears due to wind or seismic forces. The shear stress must not exceed 200 lbs. per foot for horizontal diaphragms, 250 lbs. per foot for vertical diaphragms with a maximum height to width ratio of one to one and 300 lbs. per foot for vertical diaphragms with a maximum ratio of 1 to 1-1/2. The boundary members at the edges of the diaphragms must be designed to resist flange stresses and must be adequately tied together at corners. The sheathing must be adequately nailed and have a joint pattern such that end joints in adjacent boards are separated by at least two joist or stud spaces. For horizontal diaphragms in masonry or concrete buildings there must be at least two boards between joints on the same support. Special diagonally sheathed diaphragms may be used to resist shears due to wind or seismic loads based on nail stresses but the shear must not exceed 500 lbs. per foot. In this case there is an additional requirement that, the boundary members be designed to resist in bending a uniform load, applied normal to them and acting inwardly or outwardly, equal in intensity to 50% of the unit shear. The higher value also applies to double diagonally sheathed diaphragms.

The maximum clear span of sheathing measured along the board is thirty-two inches for one inch nominal thickness and seven feet for two inch nominal thickness. However, where means are provided to limit the relative deflection between boards the span of two inch sheathing may be increased to eight feet.

Plywood used for structural purposes may be either Exterior Type or Plyscord and Plyform grades of the interior type. However, if used as exterior wall or roof sheathing or in bracing panels of small area but of vital importance, it should be exterior type or at least have an exterior type glue line. Diaphragms sheathed with plywood may be used to resist shears due to horizontal forces at the values recommended by the Plywood Association (9). In general they are nail values, increased by the normal one-third for horizontal forces, and increased again by one-eighth if width of bearing is 3 inch nominal or greater, but in either case reduced by 15% when the nail spacing is less than 4 inches. Plywood designs for other structural purposes should follow the technical data published by the plywood association (10).

Glued laminated lumber may be designed, fabricated and constructed in accordance with industry standards (11), provided all end joints are scarfed and all portions of scarfs in adjacent laminations are separated by a minimum of 6 inches. Unless the method of maintaining proper contact and alignment is specially approved, the scarfs are pre-glued. Also, since there is no formal method of obtaining lumber with the more restrictive slope of grain provisions, the upper limit of stress allowable is 2000 psi - the value assigned for a slope of grain of one in twelve.

Concrete

The design of structural concrete conforms to the standards of the American Concrete Institute (12). In general however, the shear cannot be assumed to be transmitted between contact faces of precast concrete units as indicated in the supplement to their regulations.

Additional requirements include a minimum thickness of 2-1/2 inches for self-supporting concrete slabs but not less than 1/48 of span plus 2 inches. Slabs used as diaphragms cannot be less in thickness than 1/36 the distance between supports or stiffener beams (h) and the allowable shear for slabs used as diaphragms cannot exceed that given by the formula

$$v = \frac{750}{1 + \frac{h^2}{49t^2}}$$

The minimum area of positive or negative reinforcement in beams and girders must be at least 0.6 sq. inches at any point where it is required. In calculating the minimum reinforcement in each direction in slabs the full thickness of the slab must be used. In concrete joist construction the slab thickness shall be as shown above. The joists must be bridged with bridging at least 4 inches in nominal width, at intervals not greater than 12 feet, and with a minimum area of positive or negative reinforcement of 0.3 sq. in. at any point where reinforcement is required. Column ties within 2 feet either way of points of lateral support must be spaced apart not over 12 bar diameters, 32 tie diameters, or 3/4 the least dimension of the column.

The maximum working compressive stress in concrete walls cannot exceed

$$0.2f'_c \left[1 - \left(\frac{h}{30d}\right)^3 \right]$$

The thickness of concrete bearing walls cannot be less than 6 inches nor 1/25 the distance between supports, and non-bearing walls not less than 6 inches nor 1/36 the distance between supports when shears are limited as in slabs.

The fundamental principles used in the design of reinforced gunite are the same as for reinforced concrete.

Structural Steel

Exceptions to industry standards (13) for the design of structural steel are as follows, l/r ratio of tension bracing members is not limited, provided they are so supported as to reduce sag to a minimum. All compression members carrying calculated load must conform to requirements for main compression members. Pipe columns may be designed at the same stresses as structural steel if the material conforms to ASTM A53 Grade B, or API 5L quality; otherwise structural steel stresses must be reduced by 25%. Where joint deflection is relatively important, bolt holes must be not more than 1/50 inch larger than the bolt diameter and the unthreaded portion of the bolt shall be such that all connected members have full bearing thereon. High strength bolts are permitted at normal rivet values. Welded connections are permitted for all types of loads when details are adequate and the weldments are properly inspected.

The design of members of light steel must conform to the requirements of American Iron and Steel Institute (14), except that tension stresses must not exceed the ultimate stress divided by three when commerical grade steel is used. Steel deck roof diaphragms may be used to resist earthquake and wind forces provided the sheet lies in a single plane, is made continuous by proper welding and has adequate flanges to resist the compression and tension stresses. The light steel deck resists shears only. Allowable design values are based on acceptable test information. Where there is no continuous light gauge steel sheet, shears not exceeding 50 lbs. per foot are allowed provided the connections are adequate for all stresses including those due to rotation of the sheets. Floor diaphragms or other steel roof deck diaphragms must be designed in accordance with the referenced standards and all stresses including those due to vertical loads in combination with the horizontal loads must be considered. In general, for use as diaphragms, the metal should be 18 gauge or heavier.

Light steel joists must be load tested with a sample taken for every fifty joists for each type, if the welds are not inspected or the joist is not susceptible to simple analysis. They must be bridged at intervals not exceeding eight feet and at points where there is a change of direction in the chords. This bridging must be capable of acting in compression and of transmitting a concentrated load of 1000 lbs. from any member to the adjoining members. A proposal which will probably be adopted will eliminate the requirement for such bridging when the joist is capable of carrying a concentrated load of 1500 lbs. at its midpoint or when the roof system is of a type that concentrated loads of more than 400 lbs. are extremely unlikely.

The proposal will also permit the slenderness ratio of unbraced l to r to be increased to 300. The end connections must be capable of resisting a load equal to 20% of the total design load acting either longitudinally or transversely. If joists are spaced more than five feet apart or have a span of more than fifty feet, they must be designed as for structural steel trusses.

Steel studs for bearing walls may be used only in buildings two stories or less in height.

Foundations

The requirements are not unusual. There is a minimum width requirement of 12 inches where the permissible bearing value of the soil is less than 1500 lbs. per square foot. The minimum depth requirement is 30 inches in adobe material or 24 inches otherwise, except that for one-story, wood frame buildings with rooms not exceeding normal classroom size, the minimum depth may be 12 inches in compact gravel or cemented sand or gravel and 18 inches in other sands, gravels and dense clays. Where the extent of the soils survey is such that only the type of soil is determined, the values provided for the unit bearing are quite conservative.

Permanent buildings cannot be founded on artificial fill, except when the fill has been placed under proper engineering control and the stability of the fill under seismic disturbances has been established by a special foundation investigation. There are the usual requirements for interconnection of footings or caps for buildings on piles and similar foundations, with a view to minimizing lateral displacement under seismic disturbances. Each of the ties must be designed to transmit, in both tension and compression, 1/10 of the total vertical load carried by the heavier of the footings, piers or caps connected.

Miscellaneous

Other requirements to prevent displacement during seismic disturbances or under normal vibration which may be of interest, include those for veneer, attachment of metal lath and plaster ceilings, and for the quality and application of roof tile. Also, there are requirements for the attachment of composition roofing to prevent loss and damage during wind storms. Similarly there is a specification for the size and strength of glass. Also, although not directly connected with seismic disturbances there are requirements for the design of portable grandstands and bleachers.

Operation During Construction

As public work under the laws of the State of California, the contract for construction of public schools is almost invariably awarded to the lowest responsible bidder. The bid is based on the approved plans. The supervision of the work of construction must be under the responsible charge of an architect or structural engineer or both and there must be competent, adequate and continuous inspection. Having in mind the importance of details and construction techniques in preventing loss from seismic disturbances, the contract is interpreted rather strictly.

The statute requires that the architect or structural engineer, the inspector and the contractor, each make verified reports showing of their own personal knowledge that the work has been performed and materials used and installed in every particular in accordance with the approved plans and specifications. By statute also, any person who violates any of the provisions of the act or makes any false statement in any verified report or affidavit required pursuant to the act is guilty of a felony. Of course, the phrase "personal knowledge" as applied to the architect, the engineer and the contractor means that knowledge which is the result of such general supervision of the work as is required and accepted of and from architects, engineers and contractors in the superintendence of construction of buildings and as distinguished from the continuous personal superintendence of the inspector who is continuously at the site during the progress of the work. The exercise of reasonable diligence to obtain the facts is required and anyone who intentionally remains ignorant may be chargeable with knowledge. The inspector must have actual personal knowledge that the requirements of the plans and specifications are being fulfilled. It must be obtained by his personal and continuous observation of the work of construction at the site in all stages of its progress.

Inspection by specially qualified inspectors is required for certain materials or techniques, such as masonry construction, glued laminated lumber fabrication, wood framing using timber connectors, transit mixed concrete, important steel fabrication, and welding. These inspections may be waived on small and unimportant work where job conditions warrant.

Inspection requirements are probably the most important of the requirements for public school construction. This is not to imply that contractors are unable or unwilling to construct sound buildings. Rather it is an added factor in accomplishing the desired result and should be considered as an additional precaution against errors. Good inspection pays dividends and earthquakes prove it.

Tests of materials are required throughout the code and provision for such tests must be included in the job specifications. These tests are usually performed by a commercial testing laboratory and the laboratory must certify to the effect that its responsibilities in connection with control of materials have been fulfilled. The cost of normal tests are paid by the school board as the owner. Tests can and are waived frequently when it appears that no useful purpose will be served.

General

This is a performance code and since it must of necessity be applicable to the extremes of climate and topography encountered in the State of California, it must be written in general terms. This is possible since it is contemplated that it will be interpreted and enforced on a professional plane. The code outlines minimum standards. They are treated as such by the Division of Architecture as the enforcing agency. There are no comments on designs exceeding these requirements, since they may be dictated by sound engineering judgment. In common with other codes, these minimum standards, when read by clients, tend to become maximum standards; however, here again being couched in general terms for engineering interpretation, this tendency is minimized.

The act itself and the first code under the act, then known as Appendix A, were pioneers in that they were among the first codes to be directed specifically at obtaining earthquake resistant buildings. Appendix A was known throughout the world. In its present form it (Title 21) has a broad distribution also. Probably much of this demand can be attributed to its streamlined characteristics. Nevertheless, it has been necessary to include arbitrary restrictions at times and to cover some items in more detail than is desirable. Much of this has been necessary to fit the changing character of the buildings themselves. Much pioneer work has been done. As more knowledge becomes available these restrictions can and will take a more logical form. The size, proportions and strength of bracing elements and diaphragms are under constant study and the regulations are revised from time to time to incorporate the knowledge developed.

Research

Much of the research and testing of building assemblies as described by Bolin and Maag (2) had been financed by industry. However, since 1953 the Division of Architecture has also budgeted funds for this purpose. This program is intended to develop information in those fields of materials, designs and construction which would be in the best interests of this state in connection with public schools and which is of such general nature as to be overlooked by industry research and other research organizations. The projects selected for study follow closely this policy. They are concerned with the old so-called rule of thumb design which in the case of several materials has been followed for many many years with no real knowledge as to the actual design values allowable.

The first effort was in the field of diagonally sheathed diaphragms and took the form of full scale diaphragm tests at the United States Forest Products Laboratory, Madison, Wisconsin. Similar contracts have been made with the Oregon Forest Products Laboratory, covering both diaphragms and mullion assemblies. At present projects are under way, in the field of masonry, at the University of California at Los Angeles, the University of Southern California and an independent laboratory. These projects should produce valuable information with respect to the units themselves, the mortars and grouts, their bending characteristics and the strengths of various assemblies.

Advisory Board

There is an Advisory Board for the Field Act. It consists of architects and engineers appointed by the Director of Public Works from nominations made by the California Council of Architects and the Structural Engineers Association of California, respectively, and ex-officio members representing the Parent Teachers Association, the School Trustees Association, the Department of Education, Office of School Planning and the State Fire Marshal. We think this board represents the best professional brains in the State of California. The board considers problems of new materials and research, reviews code provisions and code changes and receives appeals from any in the industry who disagree with the staff rulings. Although advisory only, its advice has never been disregarded. This board meets on the third Friday of February, May, August and November and on other occasions when necessary. Their meetings are held alternately in Los Angeles and San Francisco.

Conclusion

Since 1933 the Division of Architecture has processed plans representing about $1,800,000,000 worth of public schoolhouse construction. In a typical prewar year the volume amounted to about $14,000,000 with a low of $3,000,000 and a high of $27,000,000. The present dollar volume of plans being processed amounts to about $230,000,000 yearly.

Of course the critical test is yet to come but conclusions can be drawn from the experience of the earthquakes occuring since 1933. The damage when measured against the total volume of construction is insignificant. When measured on a regional basis it is very minor. No one has seriously questioned the integrity of Field Act School buildings.

From time to time criticism is heard to the effect that excessively high standards are required by Title 21 in the construction of school buildings. The fact that there was some slight damage to approved schools in the Kern County earthquake (15) is proof that the requirements are not too restrictive. On the other hand, the fact that some of this damage could be attributed to faulty construction, indicates that the working of the act is not yet perfected.

The purpose of the statute, as stated therein, is the protection of both life and property. Although the rules and regulations adopted by the Division of Architecture are not intended to assure absolute escape from damage to buildings, they are intended to provide safety to occupants and to provide minimum of damage. This objective has repeatedly been brought to the attention of school officials and to members of the Legislature by Anson Boyd, State Architect. Mr. Boyd insists that if school buildings can be designed and constructed to withstand earthquake forces without danger to occupants and with inconsequential damage when subjected to an earthquake of about the same severity as the San Francisco earthquake of 1906, then the aims and objectives of the Field Act as hoped for by the Legislature have been accomplished. The Imperial Valley earthquake of 1940 and the Kern County earthquake of 1952 furnish ample proof of Mr. Boyd's contention.

Bibliography

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3. Title 19, California Administrative Code.

4. Uniform Building Code of the Pacific Coast Building Officials Conference - 1949 or 1952 edition.

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Table 406(b)

Allowable Unit Stresses in Brick Masonry in Pounds per Square Inch

Compression	
Axial	270
Bending	500
Shear	
May be figured on full wall thickness	
No web reinforcement	15
Web reinforcement*	25
Or on Grout only	
No web reinforcement	50
Web reinforcement*	75
Bearing	375
Bond	
Deformed bars (A.S.T.M., A305)	80
Plain bars	40
Tension in steel	
Structural grade	18,000
Intermediate grade	20,000
Modulus of Elasticity - E_m	1,500,000
Ratio E_s/E_m - N	20
Modulus of Rigidity - G	600,000

*These values are to be used only when the shear reinforcement takes the entire shear and is spaced as required for stirrups in reinforced concrete. (See Article 7.)

Table 305

Values of Coefficient "C"

Part or portion	Value of "C"	Direction of force
Floors, roofs, columns and bracing in any story of a building or the structure as a whole	$\frac{.60}{N + 4.5^*}$	Any direction horizontally
Bearing walls, nonbearing walls, partitions, free standing masonry and concrete walls over 5 feet in height	.20 With a minimum of five pounds per square foot	Normal to surface of wall
Cantilever parapet and other cantilever walls above roofs of buildings	1.00	Normal to surface of wall
Exterior and interior ornamentations and appendages	1.00	Any direction horizontally
When connected to or a part of a building; towers, tanks, towers and tanks plus contents, chimneys, smokestacks and penthouses	.20	Any direction horizontally
Elevated water tanks and other tower supported structures not supported by a building.	.12	Any direction horizontally
Anchorage & foundations of such structures	.20	

*N is number of stories above the story under consideration, provided that for floors or horizontal bracing, N shall be only the number of stories contributing loads. This factor shall be applied to the summation of all required loads above the story under consideration. N is equal to 0 for one-story buildings and for determining load to floor diaphragms.

Table 116

Roof or Floor Diaphragms - Maximum Span-depth Ratios

	Maximum span-depth ratio	
	Masonry and concrete walls	Wood and light steel walls
Concrete........................	Limited by deflection	
Steel deck (continuous sheet in a single plane)................	4:1	5:1
Steel deck (without continuous sheet)	2:1	2½:1
Poured reinforced gypsum roofs....	2:1	2½:1
Plywood, nailed all edges.........	3:1	4:1
Plywood, nailed to supports only (blocking omitted at intermediate joints).	2½:1	3½:1
Diagonal, sheathing special.......	3:1	3½:1
Diagonal sheathing (conventional construction)..................	2:1	2½:1