1931.
NEW ZEALAND.

BUILDING REGULATIONS COMMITTEE

(REPORT OF).

Laid on the Table of the House of Representatives by Leave.

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Wellington, 23rd June, 1931.

The Right Hon. the Prime Minister.

I have the honour to present herewith the Report of the Building Regulations Committee.

J. E. L. Cull, Chairman.

REPORT.

The report is compiled in four parts, as follows:—

(1) General Report.

(2) Appendix I.—Draft General Earthquake Building By-law.

(3) Appendix II.—Detailed Recommendations for incorporation in a Uniform Building Code, comprising—

(a) General basis of designing and floor-loads.

(b) Chimneys.

(c) Construction in timber.

(d) Construction in brick.

(e) Construction in reinforced-concrete.

(f) Construction in steel.

(4) Appendix III.—Reports on Effect of the Hawke's Bay Earthquake on Buildings in—

(a) Napier.

(b) Hastings.

GENERAL REPORT.

Shortly after the disastrous earthquake in Hawke's Bay the Government set up a Building Regulations Committee, of which the personnel comprised—

Professor J. E. L. Cull, Professor of Civil Engineering, Canterbury College (Chairman);
Mr. A. G. Bush, Borough Engineer, Lower Hutt;
Mr. R. A. Campbell, structural engineer, Christchurch;
Mr. J. Fletcher, Fletcher Construction Co., Auckland;
Mr. J. W. Graham, builder and contractor, Christchurch;
Mr. G. A. Hart, City Engineer, Wellington;
Mr. J. T. Mair, Government Architect;
Mr. A. S. Mitchell, architect and engineer, Wellington;
Mr. W. L. Newnham, designing engineer, Public Works Department;
Mr. W. M. Page, architect, Wellington;
Mr. E. H. Rhodes, structural engineer, Auckland;
Mr. S. T. Silver, structural engineer, Wellington;
Mr. H. Vickerman, civil engineer, Wellington.

Secretary: Dr. M. A. F. Barnett, Department of Scientific and Industrial Research.

The Committee was given no detailed terms of reference, but was instructed to prepare a report embodying such recommendations as it thought fit, with a view to improving the standard of building-construction in the Dominion in relation to earthquake-resistance. The need for such an improvement was vividly illustrated in the appalling loss of life and property as a result of the Hawke's Bay earthquake. The Committee also advised the Government in connection with immediate building problems arising in Hawke's Bay, as a direct result of the earthquake.

The first formal meeting of the Committee was held on the 21st February, and in all it has met for thirteen full days. In addition, there have been many meetings of sub-committees, mainly of Wellington members. Through its members the Committee has kept in close touch with the views of the building interests outside, and has received many important suggestions and recommendations, notably from the Institute of Architects, the Federated Builders and Contractors' Industrial Association of Employers, the cement companies, the Brick-manufacturers' Association, and the Sawmillers' Federation, as well as from architects and engineers in private practice. The recently formed Incorporated Clerks-of-Works Association also proffered assistance, but too late for the Committee to avail itself of the offer. Any further recommendations received, however, will still be given careful consideration in the final drafting of the proposed Dominion Building Code.

The immediate concern of the Committee was the collection of data before the value of the evidence was reduced through the demolition work going on in the devastated area. Arrangements were made with the Public Works Department for plans of typical buildings and photographs to be collected. Two valuable reports were supplied—one, prepared by Mr. Brodie, covering the damage in Hastings, and the other, compiled by Mr. Harris, dealing with the damage in Napier. Both these gentlemen are officers of the Public Works Department. These two reports are reproduced in Appendix III.

It was important, in the second instance, to exercise control over the restoration work and erection of new buildings in the Hawke's Bay area. In consultation with the appropriate Government Departments, it was arranged to issue, by a Proclamation, the fundamental rules which should govern the design of buildings erected under the restoration programme. In the meantime, technical officers of the Public Works Department were made available to give the requisite help to the local bodies.

General Earthquake Building By-law.—The Committee was then confronted with the problem of what immediate action should be taken to ensure that the buildings in course of design in other parts of New Zealand should be built to a better standard than that prevailing in the past. It was recommended, as a first step, that legislation should be brought down during the emergency session of Parliament virtually requiring municipalities to make a by-law ensuring that buildings shall be designed to withstand a definite horizontal acceleration. This was introduced in section 41 of the Finance Act, 1931 (No. 2). At the same time, it was recommended that more comprehensive legislation should be introduced during the next session.

The Committee has deliberated at great length as to what should constitute the minimum requirements of strength and on the other aspects of the questions involved in securing adequate design in the future. Its conclusions have been embodied in a draft General Earthquake Building By-law, which is given in Appendix I. This draft covers the important factors of design, workmanship, and inspection during construction, and sets out what are considered to be minimum standards which should govern all construction in New Zealand, and requires that all new buildings shall be designed to withstand a horizontal acceleration equal to one-tenth of the acceleration due to gravity. Provision is made therein allowing local authorities to demand a higher standard of construction in localities which might be subject to specially severe earthquake forces. It is important that all local authorities controlling building operations take steps, in due course, to have this General Earthquake Building By-law incorporated in their own by-laws. To this end, it is recommended that the Government should issue regulations embodying this model by-law for the guidance of local authorities.

The enactment of this General Earthquake Building By-law throughout New Zealand will, in itself, lead to greatly improved design of buildings, provided the by-law is strictly enforced. Adequate enforcement implies that local authorities shall have the necessary staff to examine plans, and also that owners shall engage competent designers for the preparation of designs. It implies, further, that the work shall be supervised during construction in a very rigorous manner.

Designers in future will be expected to equip themselves with the special knowledge required to enable buildings to be designed in an economical manner to withstand earthquake forces. Such knowledge can only be gained by a special study of this branch of mechanics, which is of modern development. In order that the designing shall be both economical and effective, full use must be made of the scientific methods of design which have been evolved, notably in America and Japan, within the last few years.

The horizontal force which the Committee has decided should be used in design has been chosen as the minimum which should be adopted all over New Zealand. The selection of this value of one-tenth gravity, coupled with a very considerable increase in allowable working-stresses, has been made after due consideration of all aspects of the problem. It is impossible at the present time to evaluate exactly the earthquake risk involved in different districts, and this is a matter which requires further investigation. A request for information has been addressed to the Japanese and Italian Governments, and when this comes to hand it may be of direct assistance in the solution of this particular problem.

At the present time, also, important investigatory work is being carried on abroad in regard to the vibrations set up by earthquakes in soils of different properties and on sites variously located, and it is to be hoped that before very long we shall be able to contrast reliably the risks on, say, an alluvial plain with those on an adjacent hilly formation. At the present time opinions on this particular subject differ widely. The Committee has, therefore, put forward a minimum force to be designed against in all cases, and has left to local authorities the duty of requiring a higher value in their own districts in cases where they consider this to be necessary. The fact that the Committee has put forward a certain minimum value, with provision for a higher value at the discretion of the local authority in the meantime, must only be taken as an indication that there are districts in which a higher value will be necessary. Reference is also made in the General Earthquake By-law to the advisability of applying a higher value in the case of buildings of certain occupancy and on sites which are now known to be particularly dangerous.

Uniform Building Code.—The Committee has come to the conclusion that a general improvement in the standard of building-construction, in particular in relation to resistance to earthquake forces, can most economically be brought about by the issue of a detailed Uniform Building Code for the Dominion. The preparation of such a code would involve very many months of careful compilation, and was therefore outside the scope of the Committee's work. It is felt, however, that the preparation of a uniform code might, with great advantage to the Dominion, be undertaken by the Public Works Department, in consultation with the various interested bodies.

At present each municipality has its own set of building by-laws, many of which are now quite out of date. This seems an appropriate time, therefore, to introduce some measure of uniformity in our building by-laws. From the designers' point of view particularly, some standardization of the working stresses to be adopted for different materials is highly desirable.

A uniform building code might well include tables for use in the drawing-office in connection with the design of structures in steel and reinforced concrete. Such tables should be prepared to cover the usual floor-areas and story-heights in common use, and the standard floor-loadings which have been drawn up. Tables of this kind would relieve designers of a great deal of the tedious numerical calculation required in the design of a large building. By this means the cost of this portion of the design would be very much reduced, and this would compensate for the extra cost involved in making the intricate calculations for the moments and shears induced in the load-carrying elements of the framework when account has to be taken of earthquake forces.

While it has been impossible for the Committee, during the short time at its disposal, to compile a complete uniform code, careful consideration has nevertheless been given to certain clauses relating particularly to resistance to earthquake forces for various building-materials. These more detailed recommendations, which are set out in Appendix II, are not at present in proper by-law form. It is intended that, after being subject to expert public criticism, they should be suitably amended and eventually incorporated in a Dominion Building Code. Brief reference will now be made to these recommendations under the various headings: General Basis of Designing and Floor-loads; Chimneys; Construction in Timber, Brick, Reinforced Concrete, and Steel respectively.

There are no special features calling for comment in connection with general basis of designing and floor-loads.

The problem of earthquake-resistant-chimney design has not been solved, but a draft regulation is put forward under which it is believed that a successful type of construction may be evolved. Several promising designs have been placed before the Committee, but experience only will prove what is the best form. The use of pumice concrete offers great possibilities. Building-owners might do well to consider alternative methods of heating to avoid any chimneys at all.

In timber construction no far-reaching amendments have been proposed in current building practice. The recommendations made, however, are none the less important, and will go a long way in reducing the damage sustained by a wooden building in a severe earthquake.

The Committee has devoted a large proportion of its time to the difficult question of brickwork construction. Brick buildings have the inherent drawback that they are not amenable to precise calculation, and their stability depends essentially on the quality of the workmanship used. Nevertheless, the Committee has endeavoured to set out what it considers to be the safe limits to which brickwork construction may be carried. The recommendations of the Committee involve the elimination of construction solely in brick of commercial buildings of over three stories. In buildings over this height a framework of steel or reinforced concrete is necessary. In domestic architecture the use of three storys may be permitted in brickwork under certain restrictions, but important public buildings, such as theatres and halls, and certain institutions, such as hospitals and gaols, if over one story in height should be of framed construction.

The recommendations in regard to steel and reinforced concrete are more in the nature of standardizing what is recognized to-day as the best practice and design for construction in these materials. In connection with the clauses on steelwork, an attempt was made to draft a section which would cover the use of welding in steel-framed buildings. At the last minute, however, an important communication dealing with this question was received from the Steel Structures Research Committee of the Department of Scientific and Industrial Research of Great Britain. Consideration of this report made it appear wise, in the meantime, to withhold the issue of any recommendations on this subject, as the art of welding is now in the developmental stage and improvements may be looked for in the near future. Consideration is being given in New Zealand at the present time to developing a system for the training of welders, and this is a vital preliminary to the success of welding in a wide field of practice. The testing of personal ability of welders to carry out work in which full confidence may be placed is full of difficulties, but the successful application of welding is dependent on such a system being developed, and this will probably lead to a system of State licensing of welders. The importance of the soundness of welding in structures arises from the fact that the welded connections, particularly the ones which carry the earthquake stresses are, in general, permanently enclosed in the building. Very often they are covered in by expensive concrete and masonry in buildings which should be expected to last for many generations, and inspection and repair of the work would be a matter almost of impossibility. Certain portions of a building, notably steel roof-trusses, might undoubtedly be welded, under suitable safeguards, without any fear of future trouble. Experience in welding such portions will, no doubt, gradually build up an organization which may be entrusted with more difficult parts of the steel fabric of a frame structure.

Speaking with regard to steelwork generally, the working stresses now recommended by the Committee are higher than those current in New Zealand by-laws, but they coincide with the stresses used by engineers in Europe and America. It must not be forgotten that these higher stresses are only suitable for use with materials of undoubted quality and strength. The steel which is imported into New Zealand for general building purposes should be subject to inspection and test, in England, in the same manner as steel which is destined for use in important engineering structures. There is no obstacle to this being done, provided the matter is taken up with the merchants who handle this business. Provision has been made for a reduction of working stresses in the case where steel is used the strength of which is not fully established by documentary evidence.

A word of caution is necessary with regard to the use of the modern quick-hardening cements, for which there is at present no standardization. In the use of ordinary cement there is no such doubt.

State Supervision.—At the outset it appeared inevitable to the Committee that some adequate supervision by the State over building-work throughout the country was necessary. In view of what we now know of the earthquake risk in New Zealand and of bad building practices in vogue prior to the Hawke's Bay earthquake, it appears advisable that the State should exercise a general supervision over the building by-laws of local bodies, and should exercise such control as will ensure that these by-laws are satisfactorily enforced. The portions of the proposed Dominion Building Code which the Committee has formulated have been prepared on the assumption that legislation of this nature will be enacted.

Acknowledgments.—Communication has been established with the leading authorities in California through the Department of Scientific and Industrial Research, as well as through one of the members of the Committee, Mr. A. S. Mitchell. California has been wrestling with the preparation of a satisfactory code since the San Francisco earthquake in 1906, and more particularly since the Santa Barbara earthquake of 1925. None of its codes appear to have been entirely successful, and an influential body is now at work on the preparation of a Californian standard code. This code is not completed, but drafts of portions thereof have reached us and certain extracts have been made use of in this report. In particular, the Committee is indebted to Mr. Henry D. Dewell, of San Francisco, and Professor Bailey Willis, of Stanford University, for their assistance and advice.

This opportunity is taken of acknowledging that extracts have also been taken from the publications of the Californian Building Officials' Conference, the Canadian Standards Association, and the British Institution of Structural Engineers respectively.

Grateful acknowledgment must also be made of the valuable assistance rendered by the Building Research Station of the British Department of Scientific and Industrial Research in the preparation of a special bibliography dealing with earthquake - resistant construction and in connection with special reports of the Steel Structures Research Committee.

A certain amount of information has reached us from Japan, but we expect to receive further data from this source, and also from Italy. It is appropriate here to point out that there is great activity in Britain at the present time in building research, and an important organization has recently been set up to improve the building legislation of Great Britain. New Zealand should keep in close touch with the latest developments of other countries and make full use of them in its own legislation. Nevertheless, a certain amount of original work is required in relation to our own special problems of climate, and, in particular, to our own building-materials. Work has already been done on our timbers. Our cement is of high quality and regularity, being uniformly up to British standard, but some standardization work is desirable on our lime and bricks. With regard to steel, we cannot do better than continue the use of British steel.

General.—The precise nature of the destructive action of earthquakes on structures is obscure, and is a subject which is being investigated at the present time in all seismically active countries. Further, to quote the Japanese authority, Dr. Naito, "The science of earthquake-proof construction is so mystical, we all must do our best to uncover the nature of safe and economical building." The design of buildings to resist earthquake forces is one of the major engineering problems of the day. It follows, therefore, that the conclusions which have been reached by the Committee must be regarded as tentative, and subject to amendment from time to time as further knowledge accrues. In this connection, it is recommended that a permanent New Zealand Earthquake Investigation Committee, modelled on the Japanese organization, should be set up.

The destructive forces near to the epicentre or on the line of a big earth-movement may be so great that no building of feasible design can withstand them. All we can hope to do, therefore, is to provide a reasonable margin of safety for the usual building of the domestic or business class, and to choose such a construction that complete collapse is unlikely. In cases where important public services are involved, however, and in places of public assembly, the standard of construction should be appreciably raised. For example, in a large theatre, electric power-house, drainage or fire station, and in structures vital to the maintenance of transport facilities the design should provide a higher factor of safety against earthquake force than in structures of less vital importance.

Emergency Organization.—The Building Regulations Committee, in its deliberations, has frequently touched on the subject of danger from fire. No attempt has been made to devise regulations for ensuring greater resistance to fire, except in so far as improved resistance to structural damage automatically reduces the risk of the outbreak of fire after an earthquake. In view, however, of the grave fire risks, no apology is needed for a reference here to the need for preparedness in all our cities for a possible calamity. Some of our cities are already taking action. The organization of the Christchurch Public Utilities Committee appears to be a good model. It is suggested that emergency stations should be selected in all our cities in which copies of records, plans, &c., of vital importance, in case of a great disaster, should be filed. These depots, if possible, should be interconnected by private telephone.

The necessity for critical examination of all fire-fighting services, water-supply, drainage, electric supply, and communication systems should be obvious.

Danger of Panic.—Probably for some years to come the public of New Zealand will be susceptible to panic should a perceptible earthquake occur while large numbers are assembled in one room. Overcrowding should be strictly prohibited, and exits properly maintained and policed. Where necessary, exits should be improved, and in new construction a high standard maintained in the provision of adequate exits.

Existing Buildings.—The Committee in its work has had to confine itself to the provision of a satisfactory standard of earthquake-resistance in new buildings only, in spite of the fact that many existing buildings are unsafe from this point of view. A certain amount of work is now being done to strengthen existing buildings and to remove unnecessary and dangerous weight therefrom. This policy is undoubtedly sound, and owners should act on the best technical advice procurable. The problem really requires a systematic survey of all doubtful buildings, so that the most dangerous may be selected for immediate action.

Importance of Careful Design.—The Committee is confident that there is in this country both the desire for improved building practice and the technical skill to achieve it. In the majority of cases the additional cost will not be felt. More science and less materials are required in our city buildings. This stricture does not apply to the best of our recent construction, but even in the last year or two a great deal has been spent in features of no use and of doubtful value as ornamentation. Such added weight, during an earthquake, only becomes a wrecking force.

In the past too much of our work has been planned by men without any true sense of æsthetic values or of structural principles. The Committee therefore desires to stress the value of competent architectural advice to owners. Buildings, too, should be simple in layout. There is a slogan among engineers that a work should be "simple, cheap, and efficient." The preliminary layout of an important structure should be referred to the engineer in the early stages. He may be able to simplify the layout without any sacrifice of efficiency in the building, and thus greatly enhance its structural stability. The æsthetic treatment of the building will often be aided by the added simplicity of layout, and the construction will be cheapened. For resistance to earthquake shock the importance of simplicity of layout is very great indeed.

Competent men who visited Hawke's Bay after the disaster do not require to be told the faults of our old building practices—gross faults in design and in construction. We have the men in New Zealand who can do better things, and the building-owners of the future should know how to proceed.

Our motto should be "Better buildings at less cost." The question of cost has been steadily before the Committee, and, while the provision of resistance to earthquake force must increase the cost of the structural framework, it is felt that the reduction of useless ornamentation, and better designing, with the facilities of a uniform code, will largely, if not entirely, offset this extra cost. Also, the better construction of buildings will most assuredly be reflected in the annual cost for insurance.

The people of New Zealand must realize that the earthquake risk in this country is undoubtedly great, and that all structures, including buildings, if not properly designed and constructed to resist the destructive forces, will suffer in a severe earthquake. In future, the architect and the engineer must pay even greater attention to the importance of earthquake-resistant construction, and must co-operate with the geologist and the seismologist in the practical application of scientific principles.

APPENDICES.

APPENDIX I.—DRAFT GENERAL EARTHQUAKE BUILDING BY-LAW.

(NOTE.—A recommendation has been made to the Government that a model by-law, based on the draft given below, be issued in terms of section 363 of the Municipal Corporations Act, 1920.)

PART I.—PRELIMINARY.

Short Title.

1. This by-law may be cited by the Short Title of "The Borough Building (Earthquake Resistance) By-law, 19 ."

Commencement.

2. This by-law shall come into force on the day of , 19 .

Interpretation.

3. In this by-law, unless inconsistent with the context,—

"The borough" means the Borough of :
"The Council" means the Borough Council:
"The said Act" means the Municipal Corporations Act, 1920, together with any Acts heretofore or hereafter passed in amendment thereof or any Act passed in substitution therefor:
"Building" includes a proposed building:
"Building permit" means a building permit issued under this by-law either alone or jointly with any other by-law in force relating to the erection of buildings:
"Building for public meetings" includes a building used or intended to be used—
(i) For any of the purposes specified in section 308 of the said Act; or
(ii) As a library, museum, art gallery, or school building, if more than one story in height:
"The erection of a building" includes the re-erection of a building and the reconditioning of a building and the making of any structural alteration or addition to any building heretofore or hereafter erected, and the removal of any building from one place to another within the borough or from a place outside the borough to any place within the borough; and "erect" has a corresponding meaning.

Headings excluded.

4. The division of this by-law into Parts and the headings and/or marginal notes affixed to the clauses hereof, being intended solely for convenience of reference, shall not be deemed part hereof, or in any way control or affect the interpretation hereof.

Statutory Requirements.

5. In the application of this by-law to any building the subject of express statutory enactment this by-law shall not be deemed to require any matter or thing contrary to such enactment, or any regulations made thereunder, or any requirement lawfully made thereunder; but, except as aforesaid, compliance with any such enactment, regulations, or requirement shall not relieve any person from liability to comply with the requirements of this by-law.

Previous By-laws overridden.

6. All by-laws heretofore in force in the borough relating to the erection and use of buildings shall be read subject to this by-law, and in the event of conflict between the provisions of any such by-law and the provisions of this by-law the provisions of this by-law shall prevail.

Genera Application.

7. Except as hereinafter expressly provided, this by-law shall apply to the whole of the borough.

Copies to be sold.

8. The charge to be made pursuant to section 364 of the said Act for a printed copy of this by-law when sold separately shall be sixpence.

PART II.—BUILDING PERMITS.

Permit required.

9. (*a*) No person shall erect any building without first obtaining a building permit from the Council.

(*b*) No person shall cause or permit any building to be erected if a building permit in that behalf has not first been obtained from the Council.

Application for Permit.

10. Any person desiring to obtain a building permit shall make application therefor to the Council in writing signed by or on behalf of the person desiring to erect the building therein referred to.

Contents of Application.

11. Every such application shall set out—
- (i) The location of the building in relation to messuage and section boundaries and adjacent buildings :
- (ii) The proposed use or occupancy of every part of the building :
- (iii) Information as to the nature of the ground on which the building is or is to be placed and the subjacent strata :
- (iv) Such other reasonable information as the Council may from time to time require.

Plans and Specifications.

12. Together with every such application there shall be submitted to the Council, in duplicate, detailed plans, elevations, cross-sections, and specifications, which shall together furnish complete details of design and qualities and descriptions of all materials and workmanship, and which shall be of sufficient clarity to show to the satisfaction of the Council the exact nature and character of the proposed undertaking and the provision made for full compliance with the requirements of this by-law.

13. In the case of every building with a framework of structural steel and/or reinforced concrete, and in every other case where the Council requires it, there shall also be submitted to the Council stress diagrams, computations, and all other data necessary to show that the design complies with all the requirements of this by-law.

14. (*a*) Plans of reinforced-concrete work shall show clearly the dimensions of all members, and the size, length, shape, position, and overlap of all reinforcement.

(*b*) Plans of structural steelwork shall be complete working drawings, showing in figured dimensions the exact length and position of each part thereof in such detail that the steel may be supplied and the work fabricated from such drawings.

(*c*) Detailed plans shall be on such a scale, greater than one-eighth of an inch to the foot, as the Council may consider necessary to ensure certainty of interpretation.

Plans to be signed.

15. No plans, computations, or other data shall be submitted without first being signed by the architect, engineer, or designer responsible for their production.

Documents to be retained.

16. All applications, and all diagrams, computations, and other documents required by this by-law to be submitted to the Council not in duplicate, and one copy of all plans, specifications, and other documents so required to be submitted in duplicate, shall be retained and recorded by the Council, and shall, on reasonable request, be available for inspection by any officer of the Public Works Department, or by the owner of the building for the time being or any person duly authorized by him in that behalf.

Withholding of Permit.

17. The Council may withhold a permit if it considers that deficient information has been supplied relative to the matters hereinbefore referred to, or if it considers that the building does not comply with the requirements of this by-law, and shall in that event give the applicant notice of such withholding and particulars of such deficiency or such non-compliance, and the applicant may thereupon make good such deficiency or make such alterations in plans, elevations, cross-sections, or specifications as shall be necessary to comply with the requirements of this by-law.

Effect of Permit.

18. Every permit shall be deemed to operate as a permit to erect a building on the site shown in the application, and subject to compliance in every respect with the plans, elevations, cross-sections, and specifications submitted to and approved by the Council and not otherwise.

PART III.—GENERAL DESIGN AND CONSTRUCTION.

Building to be bonded.

19. Every building shall be firmly bonded and have its parts tied together in such a manner that the structure will act as a unit.

Ornaments to be tied.

20. All veneer-finish, cornices, and ornamental details, whether of the exterior or of the interior of the building, shall be securely and permanently attached to the structure so as to form an integral part of it.

Bearing-walls to be braced.

21. Exterior bearing-walls and other walls of unit masonry or brick construction shall be adequately tied together at the level of each floor-line from outside to outside of the structure by continuous metal rods or other bonds of continuous strength, and shall be tied to all intervening partition walls.

Footings to be interconnected.

22. Where the design of the building includes isolated footings, such footings shall be completely interconnected in two directions at right angles to each other or as nearly at right angles as the case permits. Each such interconnecting member shall be capable of transmitting either by tension or by compression at least one-tenth of the load on the heavier only of the two footings it connects, or, with the consent of the Council, at least one-tenth of the total load on all the footings divided by the number of footings.

Strength against Horizontal Force.

23. (*a*) Every building and every portion thereof shall be designed and constructed to withstand a continuously applied force in any horizontal direction equal to at least one-tenth of the weight carried by the building.

(*b*) Each part of the building shall be considered as subjected to the said continuously applied horizontal force, and shall individually be strong enough and sufficiently connected with the remainder of the building adequately to resist this force.

(*c*) The building as a whole shall be designed and constructed to resist the shears and moments of the said continuously applied horizontal force.

Assumed Weight of Buildings.

24. (*a*) For the purposes of the last preceding clause hereof the weight carried by the building shall be deemed to include—

(i) The full dead-weight of the building and any objects fastened or attached thereto or permanently placed therein or substantially permanently so placed, together with

(ii) The fraction of the transient live or floor load of the building, consisting of the aggregate of the floor-loads of the rooms thereof hereinafter specified.

(*b*) In the case of a room designed to be used principally for the storage or display of goods the prescribed fraction of the floor-load of that room shall be two-thirds of the total live load which the room is designed to bear.

(*c*) In the case of a room designed to be used principally for domestic or office purposes the prescribed fraction of the floor-load shall be not less than 20 lb. per square foot of the total floor-space in addition to any special load intended to be carried by the floor of such room.

(*d*) In the case of a room designed to be used for a purpose other than those set out in the two last preceding subclauses hereof the prescribed fraction of the floor-load shall be such as may be specified by the Council in each case, but in no case shall be less than 20 lb. per square foot of the total floor-space.

(*e*) Objects to be placed or carried on a wall and not included in the dead weight of a building shall be deemed to be part of the floor-load of the floor next below them.

(*f*) Objects to be supported or suspended from a floor or ceiling and not included in the dead-weight of a building shall be deemed to be part of the floor-load of the floor next above them.

(*g*) All floor-loads shall be considered as applied at the level of the floor on which they are carried or deemed to be carried, or of which they are deemed to be part of the floor-load.

(*h*) For the purposes of this clause the term "room" shall be deemed to include corridors and landings of staircases and every other part of a building provided with a floor.

Horizontal Shear.

25. The total horizontal shear at any level of the building shall be taken to be not less than one-tenth of the total weight carried by the building above that level, computed as hereinbefore provided.

Bracing System to be Symmetrical.

26. The main bracing systems shall be located symmetrically about the centre of mass of the building, having due regard to the relative rigidity in the horizontal plane of all elements of the load-carrying structure, or else proper provision shall be made for the resulting torsional moment on the building.

Working Unit Stresses.

27. The working unit stresses under combined vertical and horizontal forces, including those due to earthquake, shall not exceed those required for vertical load alone in the case of a building with a frame-work of structural steel by an amount exceeding 50 per centum, or, when specially approved, 75 per centum, and in the case of a building with a framework of reinforced concrete by an amount exceeding one-half of those percentages:

Provided that a percentage exceeding 50 per centum or one-half of 50 per centum (as the case may be) shall be allowed only where a building, from its monolithic nature, possesses a substantial reserve of inherent strength of a kind not easily calculated and not included in the calculations.

PART IV.—REQUIREMENTS IN PARTICULAR CASES.

Buildings for Public Meetings.

28. No building for public meetings shall be constructed otherwise than with a structural frame of steel or reinforced concrete:

Provided that this requirement shall not apply to any such building which contains no room having a total floor-space exceeding 2,500 square feet in area, and of which the height of any wall does not exceed 35 ft. measured from the mean level, or mean intended level at the time of completion of the building, of the footpath or ground adjoining the wall to the eaves, or top of parapet, or half-way up a gable, whichever is the greatest:

Provided also that this requirement shall not apply to any such building, which is entirely or substantially of wooden construction in cases where the erection of such a building of such a construction is not contrary to the provisions of any other by-law for the time being in force.

Institutions.

29. (*a*) No room of which the length or breadth exceeds 30 ft. in a building intended for use as a mental or other hospital, orphanage, hostel, or otherwise for the use as an institution for young children, aged or infirm persons, or persons subject to any form of legal detention, and having a height of more than one story, shall be constructed otherwise than with a structural frame of steel or reinforced concrete.

(*b*) Every building intended for such use as aforesaid and having a height of more than one story shall, in respect of design, construction, and materials, be of such a nature as in the opinion of the Council to offer reasonable and adequate resistance to fire.

Areas Liable to Severe Risk.

30. (*a*) The Council may, if in its opinion the whole or any part of the borough constitutes an area in which buildings may be subject to particularly severe earthquake-shocks, by resolution declare that the whole or such part of the borough be an area in which additional strength of buildings shall be required.

(*b*) The Council may, in any area so declared, require that in the designing and construction of a building an increased horizontal force be provided against, in addition to the horizontal force which a building is to be designed and constructed to withstand pursuant to Part III of this by-law.

Public Buildings.

31. (*a*) The Council may require that in the designing and construction of a building—

(i) Intended for use as a building for public meetings or of any public nature; or

(ii) In any case where in the opinion of the Council the security of important public services is involved; or

(iii) In any case where in the opinion of the Council the nature of the building or site makes it advisable so to require—

such building shall be designed and constructed to withstand earthquake-shocks, whether in the nature of a horizontal force or otherwise, greater in magnitude than the forces which a building is to be designed and constructed to withstand pursuant to Part III of this by-law.

(*b*) In any case referred to in the last preceding subclause hereof the Council may impose restrictions on the choice of materials to be used and the general lay-out of the building, in addition to the restrictions imposed by Part III of this by-law.

PART V.—MISCELLANEOUS.

Inspection.

32. (*a*) Any Inspector duly appointed by the Council shall be entitled at all times during the day or while work is being done, with such assistants as he may think necessary, to enter the premises and inspect the whole or any part of the work.

(*b*) The owner, and builder, and every person engaged in the erection of a building shall give every reasonable facility to an Inspector and his assistants to inspect the whole or any part of the work.

(*c*) In particular, the builder shall provide facilities for the Inspector to examine the foundations after excavation and immediately prior to concreting, and to examine all reinforcement or structural steel immediately before the same is covered in.

Alterations to Existing Buildings.

33. In the case of alteration to buildings which were erected or the erection of which was commenced prior to the coming into force of this by-law it shall be sufficient compliance with this by-law if the requirements hereinbefore contained are observed and complied with so far as is reasonably possible, having regard to the design, construction, and materials of the building, and the purpose for which it is used or intended to be used:

Provided that no alteration shall be permitted which will, in the opinion of the Council, tend materially to reduce the resistance of the building to earthquake-shocks, unless the building is deemed to have a reserve of strength against earthquake-shocks, and in that case no alterations shall be permitted which will, in the opinion of the Council, reduce the final strength of the building below the requirements specified in Part III of this by-law.

Change of Use or Occupancy.

34. When a building has been erected pursuant to a permit issued under this by-law, no person shall thereafter, without the previous written consent of the Council, use or occupy such building or any part thereof, or cause or permit such building or any part thereof to be used or occupied, for any purpose not set out in the application for such permit:

Provided that this clause shall not apply if the fresh purpose would not, if it had been the purpose set out in the application for a permit, have given the Council the right under this by-law to require any additional or other requirement as to design, construction, material, or otherwise besides the requirements subject to compliance with which the permit was deemed to be granted.

35. When a building has been erected pursuant to a permit issued under this by-law, no person shall, without the previous written consent of the Council, affix thereto or place therein or in any part thereof, or cause or permit to be so affixed or placed, any dead load or floor-load exceeding in weight the maximum loads assumed in making any calculations submitted to the Council in connection with the application for such permit.

36. Any consent applied for under the two last preceding clauses hereof may be granted or withheld in the discretion of the Council; and the Council in granting any such consent may impose such conditions as to the period for which the building or any part thereof may be used under such consent, or as to the period during which or the amount by which the said assumed maximum loads may be exceeded, or as to any other matter as it may in its discretion think fit.

PART VI.—OFFENCES AND PENALTIES.

Offences.

37. Every person is guilty of a breach of this by-law who—

(i) Erects any building without first obtaining a building permit from the Council under this by-law; or

(ii) Causes or permits any building to be erected if a building permit in that behalf has not first been obtained from the Council; or

(iii) Assists or is concerned in the erection of any building for the erection of which a building permit has not first been obtained from the Council; or

(iv) Erects any building, or causes or permits any building to be erected or assists or is concerned in the erection of any building otherwise than on the site shown in the application, or otherwise than subject to compliance in every respect with the plans, elevations, cross-sections, and specifications submitted to and approved by the Council; or

(v) Uses or occupies, or causes or permits to be used or occupied, a building or any part thereof contrary to the provisions of clause 34 of this by-law; or

(vi) Affixes or places to or in a building or any part thereof any dead load or floor-load contrary to the provisions of clause 35 of this by-law; or

(vii) Uses or occupies, or causes or permits to be used or occupied, a building or any part thereof, or affixes or places to or in a building or any part thereof any dead load or floor-load contrary to any condition imposed in a consent pursuant to clause 36 of this by-law.

38. Every person who is guilty of a breach of this by-law is subject to the penalties prescribed in section 360 of the said Act.

Power to demolish.

39. The Council or any officer thereof authorized by the Council in that behalf may pull down, remove, or alter any work, material, or thing erected or being in contravention of this by-law, and may recover from the person committing the breach all expenses incurred by the Council in connection with such pulling-down, removal, or alteration.

APPENDIX II.—DRAFT CLAUSES FOR INCORPORATION IN A UNIFORM CODE FOR THE DOMINION.

NOTE.—These draft clauses are not in by-law form and are subject to alteration. They are issued for discussion only, pending the preparation of a Dominion Building Code. It is intended, however, that the General Earthquake Building By-law should be adopted immediately.

Caution.—The working unit stresses now proposed are in some important instances substantially higher than those at present in general use. It is important, therefore, that a competent structural engineer be engaged on all buildings of any considerable magnitude. The engineer must have made a study of the resistance of monolithic frames to combined vertical and horizontal forces, and should have some control over the inspection during construction. The workmanship must be up to best engineering practice.

UNIFORM CODE.—GENERAL BASIS OF DESIGNING AND FLOOR-LOADS.

1. *Methods of Design.*—Every building and structural part thereof shall be designed in accordance with such detailed methods of design as are set forth in this code and are applicable to said building. In the absence of definite detailed provisions in this code for the design of any building or structural part thereof, no method of design shall be employed that will not admit of a rational analysis and that is not in accordance with the established principles of mechanics and of structural design.

2. *Loads to be used in Design.*—Every building and all structural parts thereof shall be of sufficient strength to support the estimated or actual imposed loads, including lateral forces, without exceeding the allowable working unit stresses specified in this code for the material, materials, or permissible combinations thereof, of which said building and structural parts thereof are constructed; but no building or structural part thereof shall be designed for live loads which are less than those specified herein and which are applicable to said building by virtue of its type of occupancy.

3. *Limitations of Specified Allowable Working Stresses.*—Unless specifically stated otherwise in each instance, all specified allowable working unit stresses given hereinafter for the various materials of construction, and permissible combinations thereof, are the maximum that shall be employed for the most adverse combination of dead and live loads that are hereinafter specified, or, in the absence of definite specifications relative thereto, may reasonably be expected to occur.

4. *Increase of Working Stresses for Lateral Forces.*—Wind: In resistance to the combination of wind load and other loads except earthquake, and in resistance to wind load alone, the specified allowable working unit stresses of this code for any material of construction, or permissible combinations of materials of construction, may be increased by an amount not to exceed $33\frac{1}{3}$ per cent.: but the effective section and size of any structural member shall not be less than required to resist the combination of dead and live loads alone, as specified herein, without exceeding the allowable working unit stresses specified for said combination of dead and live loads alone.

Earthquake: In resistance to the combination of (1) forces due to earthquake, as specified herein, and (2) dead and live loads, the specified allowable working unit stresses of this code may be increased by an amount as specified in the General Earthquake Building By-law; but the effective section and size of any structural member shall not be less than required to resist the combination of dead and live loads alone as specified herein, without exceeding the allowable working unit stresses specified for said combination of dead and live loads alone.

5. *Members subject to both Tension and Compression.*—Each member and its connections which are subject to resultant stresses of both tension and compression due to the action of live loads shall be designed to sustain the arithmetical sum of (1) that resultant stress giving the largest section, and (2) 50 per cent. of that resultant stress giving the smaller section. The nature of said combination of said resultant tensile and compressive stresses shall be taken to be tensile or compressive as the individual resultant stresses giving the largest section of member and connections thereof is tensile or compressive respectively. If the reversal of stress is due to lateral forces only, said member and its connections need not be designed for a stress larger than the greater of the two stresses.

6. *Members subject to Direct and Flexural Stresses.*—Every structural element subject simultaneously to both direct and flexural stresses shall be so proportioned that the sum of (1) the average unit stress on the cross-section of said structural element due to concentric axial load and (2) the maximum unit stress on said structural element due to flexure shall not exceed the unit stress f_{ca} given by the formula—

$$f_{ca} = \left(\frac{f_d}{f_d + f_b} \times f_{da}\right) + \left(\frac{f_b}{f_d + f_b} \times f_{ba}\right)$$

Where f_{ca} = allowable maximum total unit stress; f_d = computed unit stress due to concentric axial load; f_b = computed maximum unit flexural stress; f_{da} = allowable maximum unit stress in member when subject only to concentric axial loading; f_{ba} = allowable maximum unit flexural stress in member when subject only to bending: Provided that, if the unit stress f_b does not exceed 10 per cent. of the unit stress f_d no account of the bending stress f_b need be taken in the design.

7. *Eccentric Loads.*—Every structural member subject to the action of an eccentric load or force shall be designed to provide for any stress due to that eccentricity whenever the increase in unit stress due solely to said eccentricity exceeds 10 per cent. of the unit stress due to concentric axial loads alone. Should the unit stress due to said eccentricity exceed 10 per cent. of the unit stress due to said concentric axial load, the design of said structural element shall be made in accordance with the provisions of Section 6.

8. *Impact.*—The effect of impact shall be provided for in such manner and in such members as the Engineer may deem necessary, except that no impact need be considered in the design of structural members of wood.

Loads: Dead, Live, and Impact.

1. *Dead Loads.*—The dead load is to consist of the actual weights of walls, floors, &c., and is to include steelwork, casing, floor-finishings, ceilings, and all other permanent parts of the building. It shall include all loads that are to be attached to the building, such as masts, poles, signs, awnings, wires, &c.

2. *Unit Live Loads on Floors.*—The following unit live loads are expressed in pounds per square foot of horizontal projection of floors and/or roofs, and shall be the minimum live loads which shall be used in the design of buildings :—

(*a*) 40 lb. Class—
  Upper floors of private houses not more than four stories in height. (See also (*b*).)

(*b*) 60 lb. Class—
  Upper floors of private houses of more than four stories in height. (See also (*a*).)
  Ground floors of private houses not more than four stories in height.
  Bedrooms on upper floors of hotels.
  Private bedrooms in hospitals, infirmaries, and other similar buildings.
  Residential flats.

(*c*) 80 lb. Class—
  Class-rooms in schools or colleges.
  Dormitories in hospitals, infirmaries, and other similar buildings.
  Upper floors of offices.

(*d*) 100 lb. Class—
  Assembly rooms or halls, including lobbies and passages leading thereto, and as follows :—
    Churches and chapels.
    General assembly rooms in public buildings and institutions, including hospitals, infirmaries, colleges, schools, lecture halls, and similar buildings. (See also (*c*).)
    Theatres, music-halls, kinemas, and similar buildings.
    Restaurants, and reception-rooms in hotels. (See also (*b*).)
    Hotels, ground floor and below. (See also (*b*).)
    Offices, ground floor and below. (See also (*c*).)
    Floors for display and sale of light-weight goods.
    Public auction-rooms (not used for storage of goods).
    Garages for private cars.
    Light workshops.
    Rooms for storage of goods when the load to be carried will not exceed 100 lb. per square foot.

(*e*) 150 lb. Class—
  Garages for vehicles up to 3 tons gross weight.
  Medium-weight workshops.
  Theatre-stages.
  Drill-halls, gymnasia, dance-halls, and ballrooms.
  Spectators' stands, including stands on sports-grounds.
  Rooms for storage of goods when the load to be carried will not exceed 150 lb. per square foot.

(*f*) 200 lb. Class—
  Book-stores at libraries.
  Museums for heavy goods.
  Heavy-weight workshops.
  Rooms for storage of goods when the load to be carried will not exceed 200 lb. per square foot.
  Pavements surrounding buildings. When a pavement adjoins a roadway, provision also to be made for 3-ton point loads at not more than 4 ft. centres.

(*g*) Over 200 lb. Class—
  Rooms for storage of heavy goods (see Section 3), and floors to support printing and other heavy machinery or extra-heavy-weight workshops.

(*h*) Staircases and Corridors—
  The same imposed load as the floor they serve is to be provided for landings, corridors, and staircases, but need not exceed 100 lb. per square foot for staircases and landings. Every step or landing must be capable of sustaining a point load of 300 lb. placed in any position.

(*i*) Roofs—
  All flat roofs shall be of sufficient strength to carry their own weight and the loading to which they may be subjected, but in no case shall such live loading be taken at less than 50 lb. per square foot of area.

3. *Warehouses generally.*—In order to standardize designs, floors of rooms for the storage of goods shall be designed for one or other of the following loads : 100, 150, 200, 250, 300, 350, 400, 450, 500 lb. per square foot, or such higher multiple of 100 lb. per square foot as may be necessary.

4. *Design Live Load to be indicated.*—To prevent overloading in all warehouses, factories, workshops, and stores hereafter erected, the weight that each floor will safely sustain upon each square foot thereof or upon each varying part of such floor shall be placed permanently on a stone or metal tablet in a conspicuous place in the hallway of each story or varying parts of each story of the building to which it relates.

5. *Loads on Pillars and Foundations.*—For calculating the loads on pillars and foundations, the live loads given in Section 2 are to be taken in full for the roof and two floors immediately below the roof.

They may be reduced by 25 per cent. for the remaining floors.

No reduction is to be made in respect of pillars supporting storage-rooms.

6. *Minimum Loads on Beams.*—The minimum distributed live load on any floor-beam other than the external-wall beams or secondary beams is to be taken as 400 lb. per foot run. Moreover, every beam is to be capable of sustaining at any point in its span a point load of at least 3,000 lb. This does not apply to buildings of the 40 lb. or 60 lb. class, Section 2 (*a*) and (*b*).

7. *Moving Loads.*—In cases where live loads are such as to produce shock from impact or vibration, 20 per cent., or such other allowance as may be specified by the engineer to meet special conditions, shall be added to the stresses due to the effect of the static load.

8. *Lifts.*—In every case for lifts, elevators, hoists, &c., the equivalent static load at the top of the lift-shaft is to be taken as at least 50 per cent. in excess of the combined load of the actual pull in the ropes, the weight of overhead machinery, sheaves, supports, and overhead beams.

9. *Industrial and Commercial Buildings.*—The actual live loads of buildings of the industrial or commercial type, in so far as said actual live loads may be reasonably estimated, shall be used in the design of such buildings or parts thereof. Special provision shall be made for machine or apparatus loads when such machine or apparatus loads would result in greater stresses in the structural member of the floors than would be caused by the loadings specified above for such occupancies.

10. *Floors supporting Trucks.*—Public garages, and commercial and industrial buildings in which loaded trucks are to be placed, used, or stored, shall have their floor systems designed to support a concentrated rear-wheel load of a loaded truck placed in any possible position. The weight of such loaded truck shall be taken as that of the heaviest which the floor must support, but the weight of said concentrated wheel-load to be used in the design shall not be less than 11,500 lb.

11. *Arrangement of Live Loads.*—Effect of loads in adjoining stories: When the construction is such that the structural elements thereof act together in the nature of an elastic frame due to their continuity and rigidity of connections, the effect on the structural elements of any one story of live loads in adjoining stories shall properly be taken into account in the design; but the assumed simultaneous arrangement of live loading on all floors of the various stories need not be more severe than that giving similar alternately loaded and unloaded spans in each floor, and corresponding alternately loaded and unloaded vertical tiers.

Distribution of live loads on any floor: Each floor and the individual structural members thereof shall be designed for the most severe possible distribution of live loading on said floor and said individual structural members thereof.

Partial loading for trusses and trussed beams: The web members of trussed structural members of floors and roofs shall be properly proportioned for partial live loading in any one span of said trussed structural members.

UNIFORM CODE.—CHIMNEYS.

1. Chimneys shall be built of concrete, brick, concrete blocks, stone, or other approved incombustible material. The fireplace and gathering shall have a thickness of not less than 6 in. if built of monolithic reinforced concrete, or 9 in. if built of plain concrete, brickwork, or other unit masonry, and shall have no through vertical joints. All joints shall be filled with lime mortar gauged with cement. The backs of concrete fireplaces shall be adequately protected against damage by fire.

2. Except as provided below for continuously reinforced concrete chimneys, every chimney-shaft shall be adequately connected in a fireproof manner to the block so as to permit of slight movement of the shaft at this point and shall be vertically reinforced with continuous steel rods not less than $\frac{5}{8}$ in. diameter, bound together at intervals of not more than 12 in. with No. 8 black wire, all thoroughly embedded in fine cement concrete or cement mortar. There shall be not less than four such rods in single-flue chimneys, and not less than two additional rods for each additional flue. Where shafts are so constructed, the spaces between the shaft and wooden rafters or beams at roof-level shall be suitably packed with incombustible material to form a fire-stop and adequately chock the chimney. At ceiling and floor levels adequate fire-stops shall be provided, so designed that the chimney is not restrained at these points.

3. The thickness of material surrounding flues shall be not less than 4 in., and any shaft built with material involving vertical joints or any shaft of concrete other than pumice concrete shall have the flue formed with approved liners of earthenware or fireclay not less than 1 in. in thickness or of reinforced pumice concrete pipe not less than $1\frac{1}{2}$ in. in thickness. No flue, except washhouse-boiler flues, shall be less than 8 in. in diameter or 8 in. square. The flue-liners may be omitted providing the reinforced concrete is increased to not less than 6 in. in thickness and that the No. 8 gauge horizontal ties are spaced at intervals of not more than 6 in.

4. Chimneys constructed of continuously reinforced concrete from foundation to head shall have at least $2\frac{1}{2}$ in. of clearance from all rafters or beams at roof and floor levels, but shall be provided with fire-stops so designed that the chimney is not restrained.

5. If any shaft required to be chocked at the roof projects above the roof for a height of more than two-fifths of the total length of the shaft, then such projecting portion shall be adequately braced to the roof in two directions with approved iron braces.

6. These regulations shall not apply to chimneys for any furnace, steam boiler, or close fire constructed for any purpose of trade, business, or manufacture, or which might be intended for use in connection with any cooking-range or cooking-apparatus in a building when occupied as an hotel, boardinghouse, or eatinghouse, and shall not apply to washhouse-boiler chimneys. The latter may be of approved pipes of adequate fireproof quality and strength, provided the chimney-shaft does not exceed 12 ft. in length.

7. Any design of chimney involving new principles of construction or materials may be approved, provided the chimney complies fully with the standard of structural strength and safety from fire hazard provided in the above clauses.

UNIFORM CODE.—TIMBER BUILDINGS.

1. Foundations shall be either continuous concrete walls not less than 8 in. in thickness, or concrete or durable timber piles having a cross-sectional area of not less than 64 sq. in., spaced not more than 4 ft. apart under wall and sleeper plates.

2. Outside foundations shall be sunk to a uniformly solid bed, but shall not be less than 18 in. in the ground in the case of piles to outer walls, and shall have the earth well rammed and consolidated round them.

3. Where foundations are in poor ground they shall be of concrete reinforced in the following manner: Continuous external walls shall have not less than two ¾-in.-diameter steel rods embedded near the top and a similar number of ¾-in. rods near the bottom, and these walls shall be tied to the opposite external walls at intervals of approximately 16 ft. by similar concrete walls not less than 6 in. thickness reinforced with one ¾-in.-diameter rod at top and bottom, which shall be hooked over the rods in outer walls. Reinforcing-rods in external walls shall be bent round angles and all rods shall be hooked at ends, lapped forty diameters, securely bound with No. 14 gauge black wire at joints, and laid perfectly straight.

4. Piles extending 18 in. or more out of the ground shall have longitudinal walings of 4 in. by 1½ in., or equivalent section, bolted with ½ in. bolts to concrete or well spiked to wooden piles on each side of piles at ground-level, and the end bays shall have 4 in. by 3 in. diagonal braces between the bottom wallplate and these walings. Walls over 30 ft. in length shall have two similar intermediate braces in reversed directions. Similar walings and braces shall be inserted to pile rows at approximately 16 ft. intervals between external walls in each direction. If the base boards are 1¼ in. or more in thickness the outer waling may be omitted. (See fig. 1.)

5. All corners of external walls shall be diagonally braced in a horizontal plane at all floor and ceiling levels. Bracings shall extend between points distant not less than 6 ft. from the corner along each wall.

6. Bottom or bearing plates in external walls shall be not less than 3 in. in depth where piles are used or 2 in. in depth on continuous concrete foundations.

7. Bottom plates in outer walls shall be bolted to foundations at not more than 4 ft. centres. Dog-bolts and dowels shall be used for wooden piles. (See fig. 2.)

8. All external and internal walls and partitions shall be braced.

9. All floor and ceiling joists shall be properly framed to give continuous longitudinal ties not more than 9 ft. apart in both directions.

10. Gabled roofs shall be braced longitudinally. (See fig. 3.)

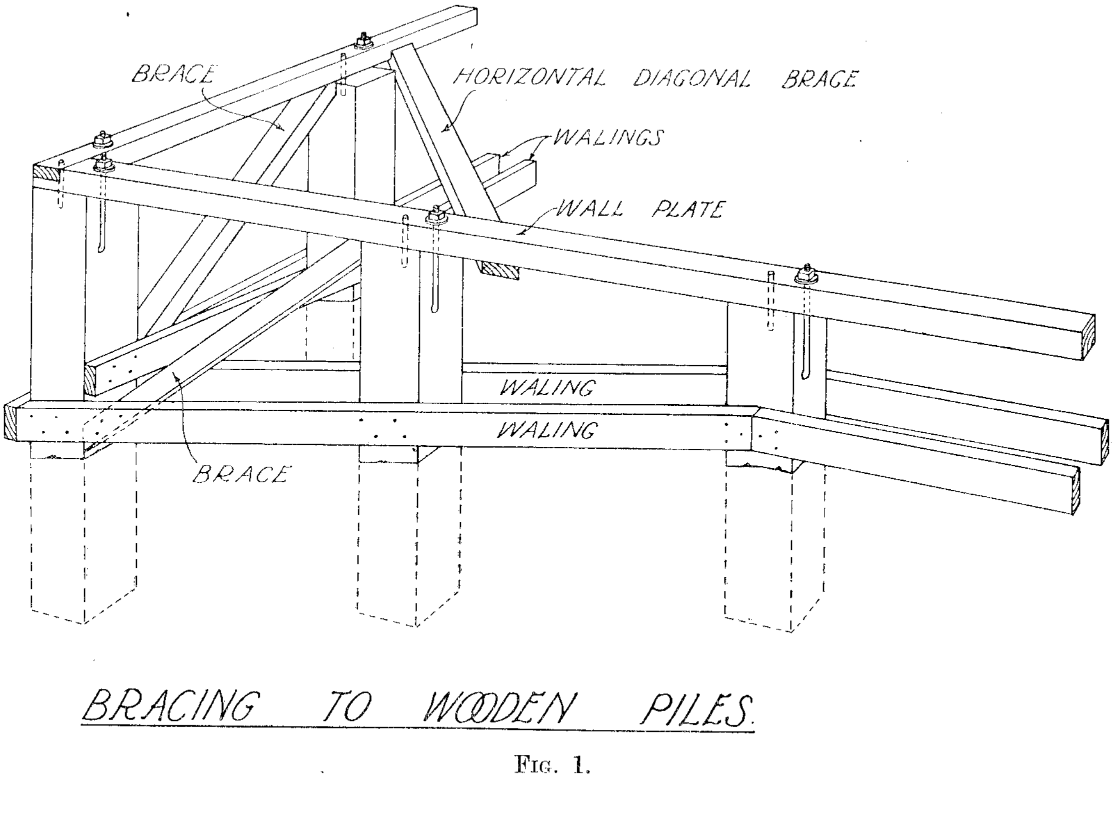


Fig. 1.

UNIFORM CODE.—BRICK BUILDINGS.

1. *Bricks.*—All bricks shall be sound well-burned kiln bricks, free from defects, and suitable in all respects for the work in which they are intended to be used. All bricks shall be of uniform size throughout any structure or integral portion thereof. Where bricks are made with frogs, these shall be confined to one side of the brick only, and shall not be of greater depth than ⅜ in.

2. *Mortar.*—Mortar shall consist of not less than one part of cement or cement-lime mixture to three parts sand, and in no case shall the cement-lime mixture contain more than one-third lime.

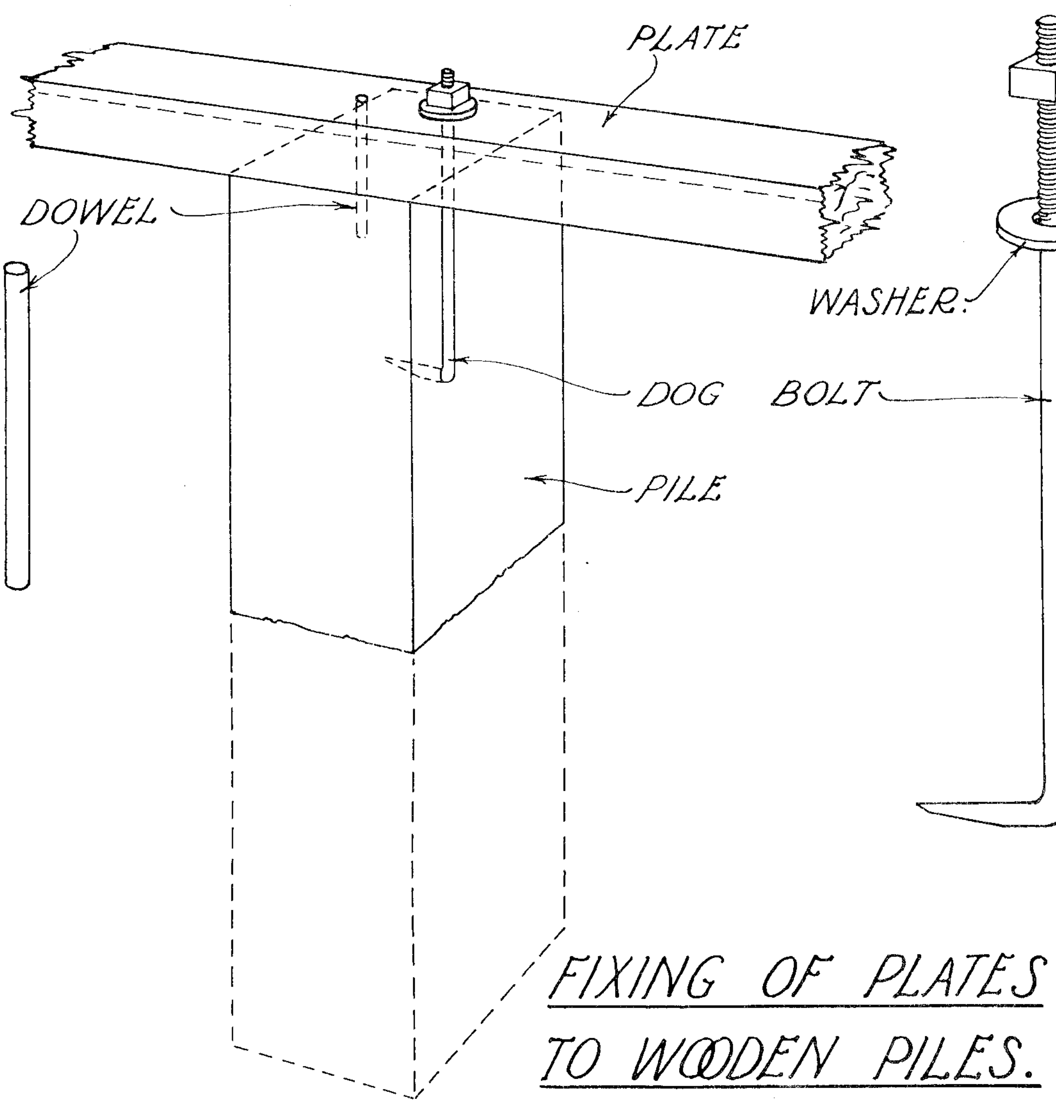


PLATE
DOWEL
WASHER.
DOG BOLT
PILE
FIXING OF PLATES
TO WOODEN PILES.

Fig. 2.

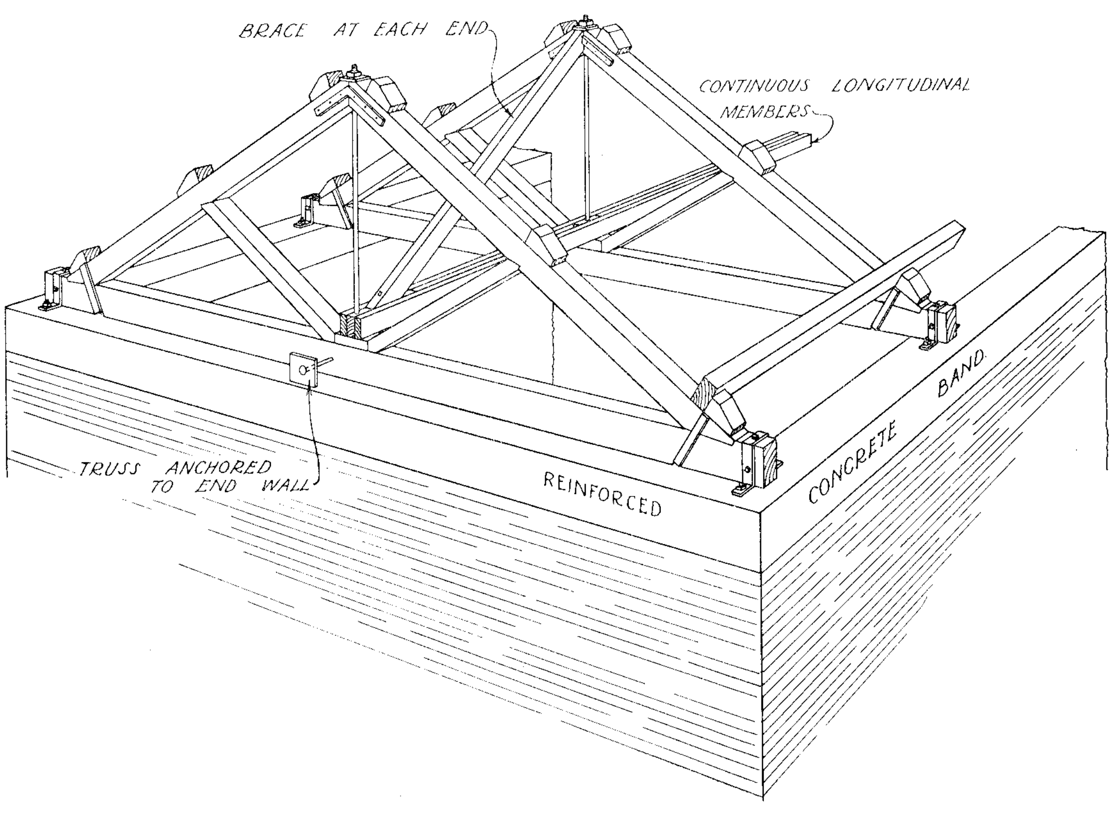

BRACE AT EACH END
CONTINUOUS LONGITUDINAL
MEMBERS
TRUSS ANCHORED
TO END WALL
REINFORCED
CONCRETE
BAND
LONGITUDINAL BRACING TO ROOFS.

Fig. 3.

These proportions shall be measured by volume, and for this purpose 1 cubic foot of cement shall be taken as weighing 90 lb. Cement shall be to British Standard Specification. All lime shall have been properly slaked. Sand shall be clean and have its grains varying in size from fine to coarse, with coarse grains predominating. Mortar shall be mixed in small quantities for immediate use only, with sufficient clean fresh water to render it of good working consistency.

3. *Bonding.*—All brickwork shall be built in English or Flemish bond where practicable, and every wall shall be thoroughly bonded to surrounding walls and piers.

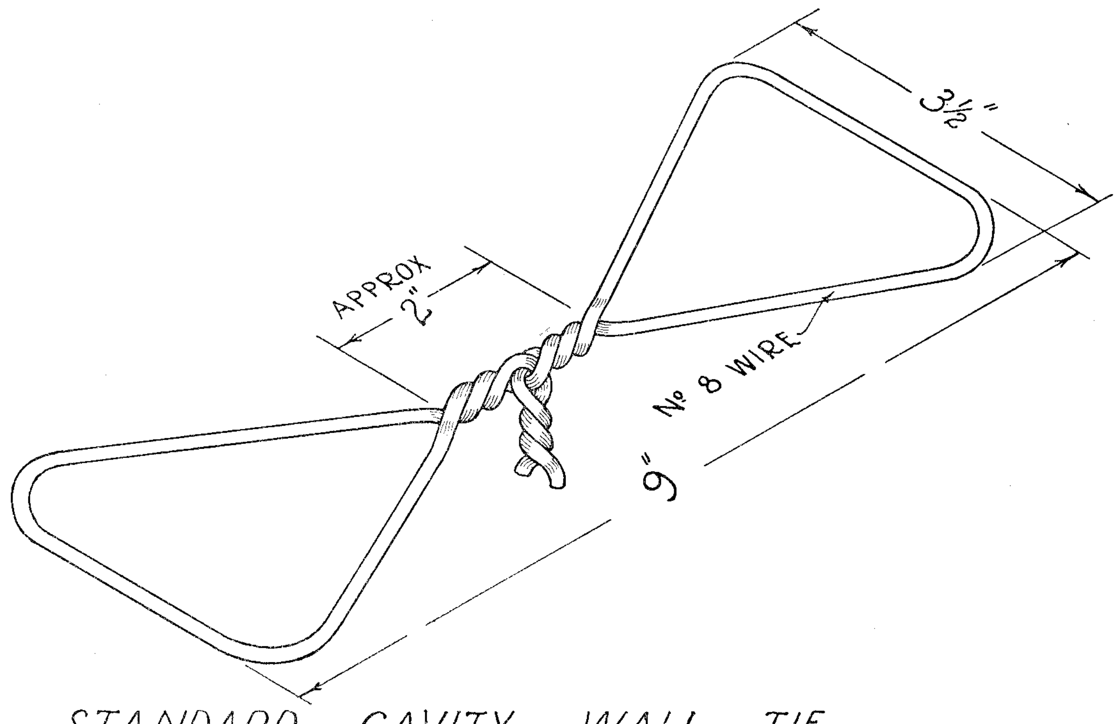
4. *Metal Bonding.*—Metal reinforcement shall be uniformly distributed throughout the thickness of the wall, and shall have an ultimate tensile strength not less than 1,200 lb. for each $4\frac{1}{2}$ in. thickness of wall, and shall have a mechanical as well as an adhesive bond with the mortar.

Transverse bonding-ties for cavity walls shall be of a standard design and so placed that they will tie strongly into the joint of the wall, and will prevent moisture from penetrating from outside to inside walls. The standard tie shall be made of No. 8 gauge wire formed into a figure of 8, 9 in. long and $3\frac{1}{2}$ in. across loops, and shall have a double twist for approximately 2 in., with ends junctioned and turned out at the centre of twist. The whole to be galvanized after fabrication. (See fig. 4.)

5. *Wetting.*—All bricks shall be thoroughly saturated with water immediately before laying, but without free standing surface water at the time they are built into the work.

6. *Laying of Bricks.*—All bricks shall be laid in true level courses, well plumbed, and with all joints completely filled with mortar. Frogs, if any, shall be laid upward and flushed solid with mortar. In placing metal bonding, a mortar bed shall first be prepared and the bonding completely embedded therein.

Metal bonding shall be built into every fourth course in the height of the wall, and additional bonding shall be built in below all window-sills and over all lintels, extending at least 18 in. beyond the opening on each side. It shall have overlapped and locked joints and shall be well tied in round corners and at cross-walls, buttresses, or piers.



STANDARD CAVITY WALL TIE.

Fig. 4.

7. *Footings.*—All footings of brick walls shall be of reinforced concrete. Where projections or openings occur in walls, footings shall be carried continuously across same. Footing reinforcements shall consist of steel rods so placed as adequately to resist lateral as well as vertical forces. Stepped footings shall be overlapped at steppings. All angles of the footings shall be adequately reinforced, and shall have diagonal reinforcing and splayed corners where necessary.

8. *Bearing-walls.*—All brick bearing-walls and cross-partitions shall have continuous ties at eacn floor and at roof-level. Such ties shall consist of reinforced-concrete bands of the full width of wall, and not less than four courses of brickwork in depth. The amount of steel shall be not less thah 0·8 per cent. of the section of the concrete required under this by-law. It shall be in the form of not less than four rods at the four corners of the band, any additional rods to be placed at intermediate positions in the sides. It shall be hooped at intervals of not more than 12 in. with $\frac{1}{4}$ in. round steel rod. Where groups of door or window openings are of less distance apart than the width of openings, lintels shall be made continuous over the series. Lintels shall have not less than 9 in. bearing on walls and be properly anchored into same, and where terminating near corners they shall be carried round same and tied into return walls. Where rafters or veranda or other roofs terminate against brick walls, such walls shall have a concrete band reinforced against lateral force. In brick walls no openings shall be placed at a lesser distance than 3 ft. 9 in. from any external angle of walls.

Brick bearing-walls shall not be built of a greater total height than 40 ft., and such height shall be measured from the mean level of the footpath or ground adjoining the wall to the eaves, top of parapet, or half-way up a gable, whichever is the greater. The height of a brick wall shall in no case exceed one and a half times the width of the building at its base. This provision shall also apply to any wing or annexe the length of which is more than twice its width.

Walls shall be deemed to be divided into distinct lengths by return or cross walls, and the length of every wall shall be measured from the centre of one return wall to the centre of another, provided that such return walls are external, party, or cross walls of the thickness required under this section and are thoroughly bonded into the walls so deemed to be divided.

The thickness of any return or cross wall shall be not less than two-thirds of the thickness prescribed for the external wall into which it bonds, and in no case less than 9 in., except that in single-story domestic buildings two 4½ in. partition walls shall be considered equivalent to one 9 in. wall.

No wall shall be deemed a cross-wall unless it is carried up to the plate level of the topmost story, and unless in each story the aggregate extent of the vertical faces or elevations of all the recesses and openings therein does not exceed 50 per cent. of the whole extent of the vertical face or elevation of the wall. Walls of strong-rooms, lift-wells, or light-areas shall be deemed cross-walls.

If a cross-wall be carried on a girder across the ground-floor story and be supported by piers and braced to the satisfaction of the engineer, such wall shall be deemed to be a cross-wall.

If a cross-wall becomes in any part an external wall, the whole wall shall be of the thickness prescribed for external walls of the same height and length.

Party walls shall be constructed of a thickness not less than 50 per cent. greater than the thickness prescribed for external walls of the same height and length.

The minimum thicknesses of brick external walls shall be as given below. Brick walls may be constructed with a 2¼ in. cavity, provided the thickness of the walls, when finished, is 2¼ in. greater than that specified below and that ties are used as specified in Section 10.

For dwellings, when the length of wall between cross-walls does not exceed 30 ft.—

Third story: 9 in.
Second story: 13½ in.
First story: 18 in.

For warehouses, offices, &c., when the length of wall between cross-walls does not exceed 50 ft.—

Third story: 9 in. with 4½ in. piers.
Second story: 13½ in., or 9 in. with 9 in. piers.
First story: 18 in., or 13½ in. with 9 in. piers.

When the length of wall exceeds 50 ft. but does not exceed 100 ft.—

Third story: 13½ in., or 9 in. with 9 in. piers.
Second story: 18 in., or 13½ in. with 9 in. piers.
First story: 22½ in.

No brick wall shall exceed 100 ft. in length between cross-walls.

When walls are thickened by piers as above, the aggregate width of such piers evenly spaced throughout the length of the wall shall be not less than one-fifth of the length of such wall. In all cases the width of the adjacent reinforced concrete bands shall be the full width of wall and pier combined.

In no case shall a 9 in. solid or 11 in. cavity external wall be built to a greater story-height than 10 ft., or any story exceed 15 ft., except that for a single-story building with trussed roof a maximum height of 22 ft. may be permitted, provided the wall thickness is not less than one-fifteenth the height of the wall.

Openings in the walls of any story shall not constitute more than 33⅓ per cent. of the length of the wall, unless the walls are proportionately thickened.

Where pipes, &c., cannot be exposed on the surface of walls, recesses or chases must be prearranged and formed when the wall is built, in such manner that the strength of wall is not affected. No chase shall be put in the 4½ in. brickwork of a hollow bearing-wall.

The permissible floor-loads in a warehouse shall be governed by the following in the case of brick bearing-walls: Except to the extent that part of the horizontal load due to earthquake acceleration at any floor is taken by properly designed and calculated internal columns, the total floor-load at either first- or second-floor level shall not exceed 4,000 lb. per foot run of building carried on two walls.

9. *Isolated Piers.*—No isolated brick pier shall be built of greater height than four times its lesser lateral dimension.

10. *Cavity Walls.*—Cavity-wall ties shall be built into every fourth course in height at not more than 27 in. centres in each row, and shall be staggered. Additional ties shall be built in to complete each row at all angles, opposite cross-walls, and round all openings. Where the reinforced-concrete band joins the brickwork the cavity shall be bridged in such a manner that the adhesion between the full thickness of brickwork and the concrete is not broken.

11. *Parapet Walls.*—Parapet walls to brick buildings shall not exceed 3 ft. in height above gutter or roof, and shall be either 6 in. thick of reinforced concrete or 4 in. reinforced-concrete backing faced with 4½ in. brickwork. Parapets shall be adequately anchored to concrete wall-bands, return walls, and piers, and they shall be suitably thickened at line of flashing and grooved to receive same.

12. *Facings.*—Where stone or other facing-materials are used for brick walls, such facings shall be of sizes to bond with brickwork, and shall be bonded and anchored into walls as the brickwork is laid.

Where facings are placed over concrete bands or piers or walls, they shall be thoroughly anchored with metal ties.

13. *Veneers.*—Where marble or other veneer is used, each unit shall be adequately anchored to the backing.

14. *Brick Panels.*—Brickwork in panels of framed structures shall be as provided for bearing-walls, save that the bond may be one course of headers to three courses of stretchers. The thickness of panel shall not be less than 9 in., except that for panels not exceeding 150 square feet in area 4½ in. brickwork may be used.

Suitable chases or nibs to receive brickwork shall be formed in the framework on all four sides of panels.

15. *Damp-courses.*—Damp-courses in all cases shall be laid of full-joint thickness in waterproof cement mortar, having strong adhesion to the brickwork, followed immediately by the laying of the first course of bricks.

16. *Beams.*—Where steel or reinforced concrete beams are built into or rest upon brick bearing-walls, the seatings for such beams, if not too far away vertically from a reinforced-concrete band, shall be incorporated in the band. Alternatively, the weight shall be distributed in the wall by a template of reinforced concrete, stone, or metal.

17. *Roof-ties.*—All roof-ties shall be adequately anchored directly at the wall-head, or, when parapets are used, to the top plate.

18. *Wooden Plates, Joists, &c.*—No wooden plate or other wooden unit shall be built or sunk into brick walls.

Where wooden plates are used they shall be laid on top of walls or on offsets or corbels of the full width of plates, and shall be firmly bolted or anchored into the concrete bands or brickwork. Wooden floor-joists shall be made continuous across the building, and at least every third joist shall be adequately anchored to the concrete band or through the masonry of the wall. Ceiling-joists shall be continuous across the building and securely attached to the plates.

At all floor and ceiling levels walls shall be tied into the building throughout their full length. Such tying may be effected by through-bolts with nut and washer on outside of masonry. When such through-bolts are not provided, the roof-structure or floor-structure, as the case may be, shall be attached to the walls in such a way as to provide tensile restraint as efficient as that provided by through-bolts. The amount of tensile stress to be provided for varies with the weight of the structure and superincumbent load. The minimum tensile value shall be equivalent to one ¾ in. iron bolt in direct tension for every 6 ft. of wall at floors and roofs. Further, the roof and floor construction shall be so designed as to provide adequate restraint against the wall moving inwards relatively to the remainder of the structure.

Where trussed roofs adjoin brick gables, a truss shall be placed directly behind the gable, and the truss rafters and purlins shall be securely anchored to the brickwork. Where ordinary rafter roofs are used, two rafters shall be bolted together and anchored to the brickwork. Where the roof oversails a brick gable, a wooden plate shall be bolted to the raking top of wall and the roof-framing shall be secured to such plate.

19. *Wooden Partitions.*—Where wooden partitions are used, they shall be strongly framed and rigidly braced and firmly anchored to the walls.

UNIFORM CODE.—REINFORCED CONCRETE.

Part I.—Materials and Workmanship.

1. *Cement.*—Portland cement shall be obtained from approved manufacturers, and shall conform in every respect to the British Engineering Standards Association Specification for the time being in force. Quick-setting cement shall not be used without special permission.

Rapid-hardening Portland cement and aluminous cement shall conform to requirements as may be decided upon from time to time.

Notwithstanding the production of certificates of vendors' tests and analyses as provided by the British Standard Specification, it shall be competent to have such further tests made, after the cement has been brought on to the works, as are considered necessary to ensure that the cement complies with the specification. If further investigation is decided upon, the cement shall not be used without permission.

Cement shall be so stored and handled at all times as to be protected from moisture from the air, or from the ground, or from any other source. It shall be so stored as to be readily inspected and so as to remain free from any other material. Any cement which has become caked or has otherwise deteriorated shall be entirely removed from the works.

2. *Aggregate.*—Aggregate shall consist of approved hard inert materials taken from sources that have furnished satisfactory material for previous concrete-work for several years, or, if from a new source, shall be thoroughly tested to ascertain whether or not it is suitable for reinforced-concrete work. It shall be well graded from fine to coarse. It shall be free from organic matter and dirt, and shall be so stored and handled at all times as to remain free from all foreign material. The maximum size of stone in the aggregate shall be 1 in. diameter, or less if specified, except in large foundation-work where stone of a larger diameter may be allowed.

3. *Water.*—Water used for mixing cement grout, mortar, and concrete shall be free from earthy, vegetable, or organic matter, and acids or alkaline or other deleterious substances in solution or suspension.

4. *Proportions.*—The cement and aggregate shall be proportioned so as to give a good workable concrete, the ultimate compressive strength of which shall not be less than 2,400 lb. per square inch at twenty-eight days. Higher ultimate compressive strength shall be provided where design assumptions necessitate same.

5. *Mixing.*—Mixing shall preferably be done by power-driven batch-mixers of an approved type. The concrete shall be mixed until it is of even colour and of uniform consistency throughout. Any concrete which shows signs of initial setting before it is deposited shall not be used in work and shall be removed from the site.

The retempering of concrete which has partially hardened—that is, remixing with or without additional cement, aggregate, or water—shall not be permitted.

Hand mixing shall be done on a hard clean, impervious, and even surface of adequate size.

6. *Reinforcement.*—All mild-steel reinforcement shall comply with the conditions and tests laid down for Class A steel in the British Standard Specification No. 15, "Structural Steel for Bridges and General Building Construction," for the time being in force.

All reinforcement of hard-drawn steel wire shall comply with the conditions and tests laid down in the British Standard Specification No. 165 for the time being in force.

Steel which is found to have developed brittleness, cracks, or other imperfections, or which is found not to comply with the specified test requirements, shall be rejected and shall be removed from the works.

All metal for reinforcement shall, before depositing the concrete, be clean and free from all loose mill scale, dust, and loose rust, and coatings, such as paint, oil, or anything which will prevent a perfect bond.

Welding shall not be allowed in any main reinforcement, except where subject to adequate tests.

Bends shall be made cold, with an internal radius of at least twice and preferably two and a half times the diameter of the bar when of Class A, structural steel, and at least three and preferably four times the diameter when the bar is of hard-drawn steel wire.

Bars above $1\frac{1}{8}$ in. in diameter may be bent at a cherry-red heat, but the temperature shall be reduced slowly.

All reinforcing shall be placed and securely fixed strictly in accordance with the drawings.

7. *Formwork.*—All formwork shall be securely braced and supported to prevent any sagging or bulging during the depositing of the concrete, and all joints shall be close enough to prevent leakage of liquid from the concrete. All forms shall be fixed to proper level and trued up immediately before depositing the concrete.

Formwork shall be so designed and constructed that it can be removed without damage to the concrete.

8. *Concreting.*—Immediately before any concreting is commenced all formwork shall be carefully examined to see that all dirt, shavings, sawdust, and/or other refuse has been removed by brushing and/or washing with a hose. All traps and temporary doors shall be carefully made good before any concrete is put into place.

The concrete shall be poured so that the coarse aggregate will not be separated from the rest of the material, and it shall be thoroughly worked and consolidated round the steel reinforcement and into all parts of the formwork so that the steel is thoroughly coated and so that no voids or cavities are left. The concrete shall be poured in layers of sufficient thickness to enable this to be done.

Care shall be taken that the reinforcing-bars projecting from concrete which has been recently put into position shall not be shaken or disturbed.

Concrete shall be placed as rapidly as possible, but where cessation of work is essential or unavoidable the break shall be at right angles to the span and in the centre of same in the case of slabs and beams, but in all cases it shall be located where the presence of the joint is least liable to lead to damage to the work during construction by uneven settlements and least liable to affect adversely the ultimate strength of the finished work. The plane of the joint shall be square to the main reinforcement. The concreting of the ribs of L or T beams, if done separately from the slab, shall stop not less than 1 in. below the soffit of the slab. Similarly, in columns it shall stop not less than 1 in. below the under-side of any connecting beam or slab.

Before depositing fresh concrete upon or against any concrete which has already hardened, the surface of the hardened concrete shall be thoroughly roughened and cleaned from all loose and foreign matter and well washed with clean water. Before concreting is commenced, the hardened surface shall be covered, preferably with freshly made mortar, composed of one part of cement to two parts of sand, about $\frac{1}{2}$ in. thick, or, alternatively, with neat cement grout freshly made. Special care shall be taken to ram the mortar and fresh concrete thoroughly up against the hardened concrete.

Reinforcement shall in all cases be covered with not less than the minimum thickness of concrete specified or shown on the drawings.

The work shall be protected, where practicable, from the direct rays of the sun and from drying winds. After concrete has set sufficiently the exposed surfaces shall be kept continuously wet for such period as shall be directed by the engineer.

No concrete shall be deposited under unfavourable weather conditions.

Care shall be taken that no shock or vibration shall reach the concrete during the process of setting and preliminary hardening.

9. *Tests on completed Work.*—After ample time has been allowed for the hardening of the concrete, loading tests on the completed structure may be called for, and shall be conducted on portions to be selected and in manner as directed.

Not more than the superimposed load for which the work has been designed, plus 50 per cent., shall be applied as a test load.

When dead loads are applied for testing, the materials used for loading shall be put on in such manner that no arching action whatever can take place.

Part II.—Design.

When forwarding plans for approval, the assumptions made in design and the working unit stresses adopted shall be clearly set out and the authority for the use of same quoted.

Notwithstanding the above clause, the following working unit stresses shall not be exceeded:—

(a) The tensile stress in mild-steel reinforcing-rods shall not exceed 18,000 lb. per square inch.

(b) The tensile stress in cold drawn steel wire shall not exceed 25,000 lb. per square inch.

(c) Direct compression in concrete shall not exceed 600 lb. per square inch.

(d) The extreme fibre stress of concrete in bending shall not exceed 650 lb. per square inch, except at points of negative moment, where it may be 750 lb. per square inch.

(e) The shear stress in concrete beams without web reinforcement shall not exceed 60 lb. per square inch, and in beams with stirrups or bent-up bars, or a combination of the two, the unit shear stress shall not exceed 180 lb. per square inch.

Where it can be shown that the mixing and placing of concrete will be carried out under the continuous control of a properly qualified inspector and that frequent tests of the concrete will be made, the above allowable unit stresses in the concrete may be increased by 25 per cent.

Floor-slabs shall in no case be less than 4 in. thick, except for approved special types of construction.

All walls 8 in. and over in thickness shall be reinforced on each face.

All openings in outer walls shall be adequately reinforced along each edge of the opening.

UNIFORM CODE.—STEELWORK.

Part I.—Workmanship.

1. *General.*—The workmanship and finish shall conform to the best practice in modern bridge-works. Materials shall have clean surfaces before being worked in the shop. The greatest accuracy shall be observed to ensure that all parts will fit properly together on erection.

2. *Straightening.*—When straightening or flattening of rolled material is necessary it shall be done by methods which will not injure the material. Sharp kinks or bends will be cause for rejection.

3. *Compression Joints.*—Compression joints depending upon contact shall have the bearing-surfaces truly faced. In the case of built-up members the facing shall be done after the member has been assembled and riveted up.

Cast bases shall be planed on the surfaces to be in contact with steel or dressed masonry.

All stiffener angles at end bearings and at points of concentrated loading on beams and plate girders shall be a driving fit against the flanges.

In all cases sufficient rivets shall be used to transmit at least two-thirds of the load at the joint. When ends are not truly faced and made to bear evenly all over the finished surfaces the full number of rivets shall be provided.

4. *Drilling.*—All rivet-holes shall be drilled through the solid metal.

When several plates and angles go to form a compound member or girder they shall, where practicable, be firmly connected together by clamps or tacking-bolts and the holes drilled through all the thickness in one operation. After being drilled, the plates and sections shall be separated and all burrs removed before they are put together again.

5. *Rivets and Riveting.*—The size of rivets called for on the drawings shall be understood as their nominal diameter before heating, unless otherwise stated.

Rivet-heads shall be of approved shape and of uniform size for the same diameter of rivet. The diameter and height of head shall be not less than the British standard. Rivet-heads shall be full, neatly made, concentric with the rivet-holes, and in full contact with the surface of the member. All loose rivets, and rivets with cracked, badly formed, or deficient heads, or with heads which are unduly eccentric with the shanks, shall be cut out and replaced by others. Recupping and caulking will not be allowed. Flattened rivet-heads and countersunk rivets may be used in certain places where clearances are required.

Rivets shall be heated uniformly red-hot from head to point when inserted, and upset for their entire length so as to completely fill the hole. Rivets when heated and ready for driving shall be free from slag scale and carbon deposit. Loose, burned, or otherwise defective rivets shall be cut out and replaced. In removing rivets care shall be taken not to injure the adjacent metal, and, if necessary, they shall be drilled out.

Wherever possible, the rivets shall be machine-driven, preferably by means of pressure machines of approved design.

The work shall be kept properly bolted together while it is being riveted, and no drifting shall be allowed, except for the purpose of drawing assembled sections into position. No drift having a diameter larger in any part than the hole in which it is used shall be allowed.

Rivet-shanks shall conform to British standard, and in no case shall rivets be allowed to be used whose mean diameter is less than the size of the hole by more than $\frac{1}{16}$ in.

6. *Turned Bolts.*—Where turned bolts are permitted and used to transmit shear, the holes shall be reamed parallel and the bolts shall make a tight fit with the threads entirely outside of the holes. A thick washer with perfectly flat faces shall be provided under each nut.

7. *Unfinished Bolts.*—Unfinished or black bolts may only be used for connections in light unimportant structures, and then only in such places as shall be decided by the engineer.

8. *Annealing.*—Excepting minor details, steel which has been partially heated shall be properly annealed.

9. *Burning.*—The use of a burning-torch is permissible if the burned metal is not carrying stress during the burning. Stresses shall not be transmitted into metal through a burned surface.

10. *Cleaning and Painting.*—All iron and steel surfaces, except such as are to be encased in concrete with a hard aggregate (not breeze or pumice) mixed in the proportion of one to two and a half to five (1 : 2½ : 5), or a richer mix, shall be painted. All surfaces, before painting or enclosing in concrete, shall be thoroughly scraped and cleaned of rust, scale, and dirt, either with sand-blast, steel scrapers, or stiff wire brushes; finally, surfaces to be painted shall be dusted off with stiff bristle brushes. Oil, paraffin, and grease shall be removed by wiping with benzine or petrol.

All painted work, including rivet-heads, shall receive at least two coats all over.

PART II.—WORKING STRESSES.

1. Subject to the provisions of Sections 2, 3, and 4, the working unit stresses shall not exceed the following per square inch:—

	lb.
(*a*) Tension on net section	18,000
(*b*) Compression on net section	18,000
(*c*) Compression on columns, struts, pillars. (See Section 4.)	
(*d*) Bending on extreme fibres of—	
Rolled shapes, built-up sections, and girders (net section)	18,000
Compression side of built-up section (gross section)	15,000
Pins	27,000
Steel castings	12,000
Iron castings—tension	3,000
Iron castings—compression	10,000
(*e*) Shearing on—	
Pins and power-driven shop rivets	13,500
Gun-driven field rivets	12,000
Turned bolts in reamed holes	12,000
Sledge-driven field rivets	10,000
Unfinished bolts	8,000

The strength of rivets and bolts in double shear is to be taken as twice that for single shear.

The shear area for rivets and bolts shall be estimated on the nominal diameter.

(*f*) Bearing on—	
Pins and power-driven shop rivets	27,000
Gun-driven field rivets	24,000
Turned bolts in reamed holes	24,000
Sledge-driven field rivets	20,000
Unfinished bolts	16,000

The bearing stress in holes for the central thickness of metal where rivets are in double shear may be increased by 25 per cent.

(*g*) The allowable unit shearing stresses in webs of rolled sections or in plate girder webs for buildings shall not exceed that given by the formula—

$$Ss = \frac{12{,}000}{1 + \dfrac{h^2}{3{,}000\,t^2}}$$

where Ss is the allowable unit shearing stress in pounds per square inch, t is the thickness of the web, and h is the vertical distance between flanges of beams of rolled section, and for plate girders the horizontal distance between stiffeners or vertical distance between flanges, whichever is the smaller. All dimensions are in inches.

Allowable Unit Shearing Stresses, in Pounds per Square Inch, in Webs of Rolled Section or Plate Girders for Buildings.

$\frac{h}{t}$	Ss	$\frac{h}{t}$	Ss	$\frac{h}{t}$	Ss	$\frac{h}{t}$	Ss	$\frac{h}{t}$	Ss
10	11,610	20	10,590	30	9,230	40	7,830	50	6,550
12	11,450	22	10,330	32	8,950	42	7,560	52	6,310
14	11,260	24	10,070	34	8,660	44	7,290	54	6,090
16	11,060	26	9,790	36	8,380	46	7,040	56	5,870
18	10,830	28	9,510	38	8,100	48	6,790	58	5,660

2. If the unsupported length l of the flange of a beam is greater than twenty times the breadth b of the flange, the maximum fibre compression stress on the net area shall not exceed $\left\{25{,}000 - 350\frac{l}{b}\right\}$ lb. per square inch.

Beams which have their compression flanges within the depth of a concrete floor may be regarded as laterally supported by the floor.

In the case of beams entirely encased in concrete at least 2 in. thick all round, properly secured to the steel beam with reinforcement, the breadth b in the above formula may be taken as the width of the flange of the beam plus the least concrete cover to the edge of the flange on one side only, but the added width due to cover is not to exceed 4 in.

In no case may the length l be greater than fifty times the breadth b.

3. Filler joists encased in a floor of solid hard brick, stone, or concrete with a hard aggregate (not breeze or pumice) mixed in the proportion of one to two and a half to five (1 : 2½ : 5), or richer mix, may be calculated, neglecting the effect of the concrete, as if the joists were stressed to 20,000 lb. per square inch for floors in which the concrete is flush on top with the joists, and an additional 2,000 lb. or fraction thereof per square inch on the joist (but not exceeding 26,000 lb. per square inch) for every inch or fraction of an inch of concrete over the top of the joists, provided that if the stress of 22,400 lb. per square inch is exceeded the spacing of the joists in inches is not less than—

$$\frac{10w\,(7c + 2d)}{(d + c)^2}$$

where w = weight of the joist in pounds per foot run; c = concrete cover to top of joist (inches); d = depth of joist (inches).

If filler joists are spaced farther apart than eight times the depth of concrete, suitable transverse reinforcement must be provided.

4. Stresses for pillars, struts, and bracing compression members shall not exceed the following per square inch :—

$\frac{l}{r}$	Allowable Working Stresses.		$\frac{l}{r}$	Allowable Working Stresses.	
	lb.	Tons.		lb.	Tons.
0–60	13,440	6	160	4,480	2
80	11,200	5	180	3,360	1½
100	8,960	4	200	2,800	1¼
120	6,720	3	220	2,240	1
140	5,600	2½	240	1,680	¾

where l=length of member and r=least radius of gyration of member.

For intermediate values of $\frac{l}{r}$ the value of the allowable stress shall be obtained by interpolation.

For pillars the ratio $\frac{l}{r}$ shall not exceed 120.

In pillars continuous over more than one story the above stresses are to be reduced by one-sixth for the top length, and for the bottom length if resting on a beam not in the foundation.

The same reduction—namely, one-sixth—is to be made for pillars of single-story length.

Stresses are to be calculated on the gross section without reduction for rivet-holes, but in no case is the area or moment of inertia to be taken as more than one and a quarter times the net value.

5. For determining the slenderness ratio $\frac{l}{r}$ the length l is to be taken as the height from centre to centre of successive beams in the various intermediate lengths; from the base of pillar to the centre of the beam for the bottom length; and from the centre of the beam below to centre of beam above for the top length, whether the beams are supported on a cap or attached to the side of a pillar. Alternatively, l may be taken from floor-line to floor-line for the intermediate floors. Where the depth of the upper beam in any story exceeds one-twelfth of the story-height, such excess may be deducted from the length l of the pillar as given above.

The greater value of $\frac{l}{r}$ shall be taken considering both axes. Where l is the same for both axes, the least r shall be taken in determining the safe stress. Where l differs for the two axes, the r and $\frac{l}{r}$ applicable to each axis shall be taken.

APPENDIX III.—REPORTS UPON INVESTIGATIONS OF DAMAGE BY THE EARTHQUAKE OF 3RD FEBRUARY, 1931, AND SUBSEQUENT SHOCKS.

(a) NAPIER.

By A. G. Harris, B.E., A.M.Inst.C.E., Public Works Department.

In making a choice of buildings for individual investigation an endeavour has been made to cover typical examples of the various classes of construction used, and also to cover typical successes and failures in those classes.

The buildings in this area may be divided into the following classes :—

(1) Buildings of wood :
(2) Buildings with brick bearing walls :

(3) Buildings with reinforced concrete frames:
(4) Buildings with structural steel frames.

There was considerable overlapping of types, and there are in this area buildings which embody two and sometimes three of the above classes.

(1) BUILDINGS OF WOOD.

Generally speaking, solidly constructed wooden buildings stood the shock well. In dwellings the chief source of trouble was the foundation, particularly in Napier South, where the subsoil is silt and there was considerable earth-movement. Concrete foundations were seldom reinforced, and many cases of destruction of this type of foundation were observed. In timber-pile foundations there was often inadequate connection between the plates and piles, and the houses were thrown off the piles. Where high pile foundations were used there was often insufficient bracing to the piles.

At Port Ahuriri several timber wool-sheds suffered badly. Many of these had R.S.J. beams and columns supporting a second floor, the exterior walls being expected to take all lateral thrusts. These suffered extensive damage, and the necessity for the provision of adequate interior bracing is indicated.

With regard to wooden shops, there were no examples of a soundly constructed building suffering more than minor damage. There were a number of this type in the fire area about which all evidence has been destroyed. In large wooden buildings where wings had been used there was considerable damage at the junctions, owing to the tendency of the parts to vibrate in opposing directions.

(2) BUILDINGS WITH BRICK BEARING-WALLS.

There were many examples of brick dwellings of one or two stories which suffered practically no damage. Several examples of failure can be attributed to the site—*e.g.*, a house on the edge of the Bluff Hill face and another on a high spur at the other end of the island.

Out in the country on the foothills there were several well designed and constructed brick dwellings which were practically destroyed, but all of these were close to extensive earth-movements and must have suffered very severe shocks.

A dwelling, on account of its compactness and the light loading of the walls, is better able to withstand earthquake-shocks than other types of brick buildings, and observations in this area indicate that dwellings up to two stories may safely be constructed in brick, but the suitability of the site *must* be considered.

In the case of larger brick buildings there were many examples of failure, and, while many of these failures can be traced to faults in *details* of design and construction, the matter of *general* design must be taken into account.

With regard to general design, the evidence in Napier demonstrated the danger of erecting tall buildings, depending on brick bearing-walls for support, in which portions of different heights abut one another. Also, the dangerous wrecking effect of heavy concrete ceilings and heavy tiled roofs was very apparent.

With regard to faults in details of design and construction, the following factors were responsible for much of the damage:—

(1) Insufficient footing-area in foundations:
(2) The absence of ties across foundations:
(3) The use of timber interior partitions inadequately secured to the walls:
(4) Poor mortar and inefficient band-course reinforcement:
(5) The support of heavy roofs on piers or walls too thin to withstand the racking effects produced:
(6) The use of heavy brick shop-fronts with totally inadequate anchorage to the main body of the building.

Associated with the above, we have many examples of poor workmanship, but as a factor contributing to failure this must not be overstressed and the factors enumerated above lost sight of. The matter of poor workmanship can easily be taken in hand by enforcing stricter supervision, but the matter of design requires careful revision of what were hitherto in this town generally accepted principles, and the need for this is liable to be overlooked if too much of the damage to brick buildings is laid at the door of poor workmanship.

General Observations.

1. *Foundations.*—No serious foundation troubles were observed on the hills where the subsoil is limestone or in those parts of the flats where the subsoil is shingle. Where the subsoil is silt there were many examples of settlement, and in one case, where serious settlement occurred, the designed loading was 2 tons per square foot, indicating that for earthquake conditions this figure is too high. Trouble also occurred owing to omission of any foundation ties across the building, and the provision of some form of reinforced-concrete tie in such cases is essential.

2. *Mortar.*—Old lime mortar had perished badly, particularly in chimneys. The lime-cement mortar used latterly appears sufficiently strong to develop the full strength of the bricks. One of the chief troubles has been that the bricks here are very porous, and there is always difficulty in getting bricklayers to wet them sufficiently, with the result that the mortar does not bond well with the bricks. With regard to filling of joints, this has in many cases been poor, particularly in the case of vertical joints. Many cases of bricks laid with the frog down were seen.

3. *Bond.*—The popular bond here is one course of headers to four or five courses of stretchers. One 42-ft.-high solid 22½ in. brick wall which is still standing was laid in English bond with very poor mortar, which seems to indicate that bond is almost as important as mortar. The use of an orthodox bond should be enforced in all new work.

4. *Cavity Walls.*—All manner of cross-ties have been used in cavity walls, the most effective being the figure 8 wire tie, but even this was not sufficient to prevent the spalling-off of the exterior wall in some cases. The use of a strip of metal to close the cavity when pouring the band course has been popular, and this should be discouraged, as it weakens the bond of the band to the brickwork.

5. *Bonding-metal.*—Bonding-metal was very sparsely used, and where used, wire-mesh strips were most popular. A few examples of expanded metal were seen. The omission was most noticeable at corners and in narrow panels between openings. In older buildings flat strips were much used. The average spacing was every nine or ten courses.

6. *Band Courses.*—The effectiveness of band courses in holding a building together was well illustrated in many cases. These, however, were invariably placed at floor and ceiling levels only, independent of the height of the wall. Where there are no window-openings a second band could well be placed in a high wall. The universal size for band reinforcement was ¾ in., and in only one case was this size increased when the walls were exceptionally long. Very few cases of bands being provided at the top of partition walls, connecting the main bands, were seen.

7. *Gables.*—Gables invariably proved a weakness under existing methods of tying them in, and many cases of gables being pushed out by purlins were seen. Hip ends to roofs should be preferred, wherever possible.

8. *Parapets.*—Brick parapets, together with gables and heavy façades, were responsible for loss of life and should be discouraged, and where used, the height should be strictly limited. There was one case of a parapet on a party wall falling on a roof-truss, displacing the wall-plates underneath, and so pushing out the opposite wall of the building by a thrust transmitted through the trusses.

9. *Damp-courses.*—Several examples of movement in bituminous band courses were seen, and a movement of about 8 in. in one case was reported to have taken place. In one building in Napier the band courses were burned out, and this assisted in subsequent failure of curtain walls.

(3) BUILDINGS WITH REINFORCED-CONCRETE FRAMES.

This type of construction has proved eminently successful, and there are many examples of reinforced-concrete buildings which have suffered very little structural damage. Had it not been for the fire, there would have been many more monuments to the success of this type of building. There was only one outstanding failure.

1. *Foundations.*—Invariably, spread footings were used, taken down to shingle. In many cases central piers were isolated, and the provision of a network of tie-beams at footing-levels would have been a desirable feature, though no trouble could be traced to their omission.

2. *Basements.*—No cases of failure in basements were seen, either to the structural frame or to floors and walls. All basements examined were, however, on good shingle foundations.

3. *Columns.*—Most of the damage observed occurred in the columns, and particularly in ground-floor columns. Some strenghtening of the junction of columns and floor beams is indicated as being desirable, and the provision of small haunches or haunch-rods in the walls at these points is worth considering.

4. *Partition Walls.*—Where integral reinforced-concrete walls were used very little trouble occurred, but brick partition walls in many cases were damaged. Concrete-block walls were used in some cases, and these stood better than brick. Concrete walls are to be preferred.

5. *Light-wells.*—Where light-wells were introduced and the continuity of the building broken, they proved a source of weakness; but this was avoided in several cases by continuing wall-beams across the wells.

6. *Shop-fronts.*—Almost invariably encased R.S.J.s were used across shop-fronts, and this does not seem to have proved a source of trouble. The difficulty with shop-fronts has been to provide the glassed area insisted on by owners without sacrificing lateral rigidity of the front of the building. In many cases the owner has prevailed, and the disastrous result has been well illustrated in certain shops in Napier. In this part of a building, more than anywhere, on account of absence of walls, it is important that columns be substantial and well fire-protected, and that some form of bracing be introduced.

7. *Cantilevers.* — There is only one example of a cantilevered veranda on a reinforced-concrete building. This one suffered no structural damage.

(4) BUILDINGS WITH STRUCTURAL-STEEL FRAMES.

The only example of this type of construction in Napier was completely gutted by fire. There was no evidence of any extensive earthquake damage to the main frame.

GENERAL.

Maximum Accelerations.—The results of investigations in this direction have proved very disappointing. Carbide generators in a shed in the Acetone Company's works were overturned, and the horizontal acceleration required is 0·27 g (g = acceleration due to gravity); but it must be remembered that these were bunched together in a shed and were probably subjected to other influences. One cylinder had some heavy top gear omitted, and this one gives a value of 0·37 g. Monuments in cemeteries gave widely divergent results, from as low as 0·17 g to as high as 0·5 g, but in several cases there were marks showing that the monuments moved on their bases before overturning.

With regard to vertical acceleration, nothing worth recording was observed.

Several electric-light pendants were smashed by swinging against the ceiling, but were very short (under 2 ft.). I was told of one about 4 ft. 6 in. long which was broken, but this was in a building later destroyed by fire.

The breakwater slip shows an interesting example of material falling well clear of the base of the slip. It appears to indicate a heavy horizontal thrust.

As evidence of a vertical thrust, chimneys which fell clear of the eaves were investigated; but this could have been caused by a horizontal thrust when the chimney had reached a horizontal position in falling.

Ground-movements.—Several bridges showed remarkable displacement of piers with no corresponding earth-movement showing on the surface. This, however, may have taken place well below the surface, the movement being damped out in the surface shingle.

Public Utilities.—The water-supply was seriously interrupted by the first shake, and the lack of water greatly hindered fire fighting. The cast-iron mains were badly fractured at junctions, and at joints the lead packings were disturbed, allowing extensive leakages. The reservoirs on the hill were badly fractured, and the high-pressure tower on Bluff Hill was overturned.

The sewerage system was also badly damaged, but sufficient lengths have not yet been opened up to enable definite conclusions to be made as to the behaviour of the various classes of pipes used. In three lengths opened up, on silt, 5 ft. to 6 ft. deep, earthenware pipes, whether on a concrete bed or not, were badly fractured, and concrete pipes without a concrete bed were much less damaged.

Chimneys.—Only a few chimneys were left standing, and these include several reinforced-concrete ones. In many cases the failure of massive chimneys caused very extensive damage to the building.

(Note.—This general report was based on a detailed analysis of the damage sustained by a large number of individual buildings. Full particulars of his detailed investigations, illustrated by photographs and plans, were forwarded to the Committee by Mr. Harris.)

(b) HASTINGS.

By A. Brodie, B.E., M.Sc., Public Works Department.

The three shocks of major intensity occurred: (a) 11 a.m., Tuesday, 3rd February, 1931; (b) 9 p.m., Tuesday, 3rd February, 1931; (c) 1.30 p.m., Friday, 13th February, 1931.

It appears that the tremors of 3rd February were of two distinct types—viz., a vertical wave or severe upward jolt, and a horizontal wave. That these waves struck Hastings from varied directions is definitely proved by evidence from several distinct sources—

(a) Monuments in local cemeteries exhibit the most convincing proof. Columns fell in the general directions of north, south, east, and west. Portions of monuments were projected from their bases. A marble slab thrown forward, turned completely round, falling face up on the ground.
(b) From marks on the plaster it is apparent in the High School that two pictures on walls at right angles to each other both oscillated through angles of 60 degrees.
(c) The collapse of buildings along transverse axes in streets running at right angles.

These phenomena are produced by the complex principal types of waves, longitudinal and transverse, and serve to indicate the severe and involved forces that constitute an earthquake. The two severe shakes of 3rd February wrought the greater part of the damage, although that of 13th February was of comparable intensity. Thus structures that have endured these shocks and the subsequent intermittent tremors of somewhat less, but nevertheless severe, intensity have survived a searching test, the results of which can therefore be accepted with every confidence.

Subsoil.—In the Hastings business area foundation conditions are such as to accentuate or intensify the wave-action. Generally speaking, west of Market Street the subsoil is wet pug clay with ground-water level at an average depth of 3 ft. below the surface; east of Market Street fine blue running sand with water at a depth of 4 ft. to 5 ft. is encountered. The area was originally a swamp.

General.—Well-known considerations of general applicability that need no expounding are—

(a) Site: Made ground, and particularly situations having adjoining substrata of different types, are to be avoided.
(b) Foundations should preferably be on rock; otherwise deep substantial footings well tied together and reinforced, giving low uniform unit soil-pressures, are recommended.
(c) Shape: The plan should be compact, regular, and without attachments or "wings."
(d) Superstructure should be of homogeneous construction and of uniform height, without heavy cornices, parapets, &c.

WOODEN BUILDINGS.

In this area actual structural damage to timber dwellings was not very pronounced. This is mainly accounted for by the fact of the area being flat and buildings constructed close to ground-level. It is noticeable that wooden buildings on sidling ground or elevated house-blocks almost invariably suffer through insubstantial bracing of the foundation-piles. Under no circumstances should a building of any type be built partly on original and partly on made ground, even though the latter has been down a number of years.

The racking effect, on the ground floor in particular, of multiple-storied timber construction is very apparent in some cases, and supports the opinion that the customary system of diagonal bracing is seriously at fault. The practice of breaking the diagonal-bracing members at every wall-stud gives a very inefficient system. For a single story it appears much preferable, from a structural viewpoint, to keep the diagonal brace in one piece and to cut the studding. For multiple stories, where a greater vertical load is imposed, a more expensive but thoroughly effective alternative is to check the stud to give a square thrust face to the diagonal stress. This weakens the stud against bending, but its resistance in this capacity is so slight as to be negligible.

As noted during the Murchison earthquake, 1929, continuity of structure in the frame of buildings over one story is a desideratum.

Heavy plastering and architectural ornamentations on ceilings are a source of danger. Plaster applied to a surface of expanded metal adheres most satisfactorily. On ceilings and walls the use of wire netting over the laths is beneficial in preventing falls of plaster.

In this district tiles and slates were not dislodged to any extent, practically all the damage being caused by falling chimneys.

A number of concrete chimneys survived the earthquake, but there does not appear to be one original brick chimney standing, save a short one built into the brick bearing-wall at the Parkvale School. Built in 1919, it projects about 3 ft. 6 in. above the eaves, and appears to be of cement mortar. The provision of four small L irons, with bands every 2 ft. 6 in. to 3 ft., at each of the outer corners of a brick chimney will in most cases provide against the collapse, if not the fracture, of the stack.

It must be realized that the severest stresses are concentrated in the ground-floor frame of multiple-story structures. Hence, in wooden shops, as the adoption of extensive display windows precludes all possibility of adequate bracing on the property-line, provision must be made for stiffeners at the rear of the window areas. Interior cross-partition and end walls need to be strong and substantial.

Plate-glass windows must not be under restraint in their fittings. Ample clearance, according to the flexibility of the building, should be allowed to take up elastic motion of the frame, both longitudinally and transversely.

In conclusion, it may be stated that good foundations, ample bracing, and careful construction will ensure wooden buildings against earthquake damage.

STRUCTURES WITH BRICK BEARING-WALLS.

Whereas brick, in general, as a construction medium has been roundly condemned, the workmanship and design, and not so much the material, is deserving of the severest criticism. Outstanding examples of varying magnitude of this type of construction are in evidence to discountenance the deplorable impression arising from a superficial inspection of this area.

Foundations.—Naturally, the first requisite for successful brick construction is a rigid foundation to tie the base of all bearing-walls. In this area a reinforced-concrete spread footing 2 ft. 6 in. to 4 ft. wide, according to the load to be carried, has given every satisfaction. From this the brick bearing-wall is stepped up without any cavity to the damp-course above ground-level. Where this type of foundation has been used there is little indication of weakness or failure at the damp-course. On compressible subsoils and on water-logged strata, where spread footings are required, more attention needs to be paid to the provision of foundations of such dimensions as to give uniform distribution of pressure.

Bond.—A widespread practice that should be discouraged is the use of unorthodox bond. For instance, 9 in. walls are built with three courses of stretchers and one of headers in sequence. English bond can be used in a wall as thin as 9 in., and gives greater protection against failure from the "whipping" action induced in panels.

Mortar.—Straight cement mortar appears to be warranted, even in curtain walls, but experiments are required to test whether the full strength of the brick can be developed through the bond. From inspection of existing work, it appears that the mortar and brick are well bonded on that portion of the brick upon which the mortar is plastered, but the opposite face does not always adhere. This difficulty should be surmounted by adequate soaking of the bricks, working the brick into its bed, and working the mortar in the joints with the point of the trowel.

As it is unnecessary to attain a mortar any stronger than the brick used, it is suggested that research should be carried out under working-conditions to investigate the proportion of lime that may be incorporated to produce a more fatty mortar and still give sufficient strength and bond.

Bonding-metal.—The use of bonding-strips or expanded metal has been very haphazard. In the majority of buildings it has not been used at all, in others at every twelve courses, if and when remembered, again at quoins only. With the soft friable lime mortar in common use the omission has not been of much moment.

Bonding-metal strips form a cleavage-plane, and are not very effective once severe fracture has occurred. They are most effective in resisting longitudinal stresses in the wall.

Expanded-metal bond, on the other hand, forms no plane of weakness, and, provided the mortar is sound, it will in most instances prevent complete collapse of a severely ruptured wall. However, it is rather less efficient than the metal band in behaviour under longitudinal stresses in the wall.

It is recommended that expanded metal be used at least every six courses or wire mesh every four courses.

Cross-ties in cavity walls are notably lacking. Their liberal use should be insisted upon.

Reinforced-concrete Bands.—Next to dependable foundations, of paramount importance are the reinforced-concrete bands. Instances have been encountered where plain concrete has been used; and again, where it has been considered merely an architectural feature, the brickwork has been cement-plastered to give that appearance. It is essential that the band be continuous round the whole building, otherwise its object is defeated. A band should be situated at each floor-level and immediately under the wall-plate. Common practice is to reinforce the under-side alone; but the wall develops a bellying movement, like a sail, and steel should be placed on the two sides to take this lateral bending. Particular attention must be paid to the junction of bands at corners, as this point has been a frequent source of failure. A substantial reinforced fillet is beneficial.

It has been objected that the band forms two planes of weakness on its two horizontal faces. For the lower face this is obviously incorrect, as the concrete is poured directly upon the rough brickwork. The upper surface may be chipped or scraped before the concrete has set for bonding with the next course.

Where the distance between successive bands has not been greater than about 12 ft., damage is non-existent or negligible. There are outstanding instances of greater height, but the above limit is recommended for safety.

In two collapsed walls it is noted that the cavity has been carried up through the band.

Floor Systems.—Floor beams or joists must be securely anchored into the reinforced-concrete bands. A reinforced-concrete floor system with beams monolithic with the bands undoubtedly gives most satisfaction and a positive means of tying the walls.

Partition Walls.—Brick partition walls, unless built into concrete floors above and below, require a reinforced-concrete band securely tied into the bands of the main walls.

Window Areas.—A consideration of more importance in brick construction than any other type is the avoidance of window or door areas near corners of the building.

Gables.—Gable end-walls require careful treatment. Tying securely to roof-joists, rafters, or roof-principals, with anchor-bolts and heavy washers, has proved successful, but is not an infallible remedy unless the roof is well braced against the longitudinal movement and the gable not too extensive. A light reinforced-concrete band over the larger gable-walls will give a more positive medium into which to sink the anchor-bolts.

Roof-trusses.—Weak anchorage of wall-plates to band frequently caused collapse by allowing walls to spread. Similarly, roof-trusses insecurely attached to the bands or merely bedded in a course of brickwork were a primary cause of failure. No claim of superiority can be ventured for any particular type of truss, the light and the heavy construction being equally associated with successful and unsuccessful resistance to the shocks. In no case can failure be attributed to the trusses directly, except in so far as inadequate anchorage was concerned.

That the most satisfactory type of roof-truss to use with brick bearing-walls is one of the knee-braced type, there seems no doubt. In the three instances in which it has been used locally it appears to have had a considerable bracing effect and been a definite factor in preserving the stability of the walls.

Façades.—The earthquake has revealed a striking feature in building-construction that is current in probably all New Zealand towns. This is the provision of massive and imposing architectural façades of brick or concrete, disguising flimsy interior frames of timber or light brickwork. In most cases no effort was exerted to tie these adequately to the framework, so that the front portion crashed to the ground or became dislodged and had to be demolished. Owing to the heavy strains that would be induced in the structure and the difficulty of tying the two together effectively, a heavy ornamental façade to a timber frame should be prohibited. It is not sufficient to rely upon brick interior and end walls to tie back these façades unless the bands of each are thoroughly interlaced.

Parapets, &c.—The peril resulting from high parapet walls balanced above a building, of heavy cornices, and of projecting pediments needs no emphasis to one who has visited this area. It is recommended that all parapets be of reinforced concrete continuous from the band, or, if of brick, limited to four courses above the band.

Pillars, &c.—Brick piers and pillars, &c., should not be tolerated under any circumstances, as, by the nature of the material, it is not to be expected to withstand the heavy shear and bending stresses induced by an earthquake.

Towers.—The erection of towers warrants serious consideration in all types of construction, but is most reprehensible in brick designs. As an inelastic construction, it is least adapted to structures of irregular elevation.

General.—Whereas in timber and reinforced-concrete construction the oversight of one important point will, in all possibility, result in fracture and damage to a greater or lesser extent, the neglect of one cardinal principle in brick design is liable to precipitate complete collapse and disaster. Hence, the necessity for competent and careful design and workmanship cannot be overstressed. No examples of buildings of this type over two stories high are available here, but the impression gained is that every confidence can be placed in its behaviour at least to these dimensions.

COMPOSITE BRICK CONSTRUCTION.

Numerous examples of composite construction of brick with reinforced-concrete framing illustrate the success of this combination.

Slight diagonal shear-cracks have developed in the plaster in many cases, but in a well-constructed frame brick curtain walls have proved perfectly safe. Diagonal bond might be beneficial in preventing or reducing cracks in curtain walls.

General practice appears to favour solid curtain walls with a cement-plaster coat on the exterior surface to prevent penetration of moisture.

The use of poilite or galvanized-iron sheets under the band to bridge the cavity in brick curtain walls leads to malpractice, in that these sheets frequently cover the greater portion of the wall, leaving only a narrow external strip for bonding the band and the brickwork.

REINFORCED-CONCRETE CONSTRUCTION.

With few exceptions, reinforced concrete has withstood the earthquake with remarkable success Three distinct types in this district, when well designed and well constructed, have behaved admirably,—

(*a*) A building with mushroom head columns, flat slab, drop-panelled construction, with brick curtain walls (three stories and basement) survived almost without a flaw.

(*b*) Current practice in plain beam and column frame with reinforced-concrete curtain walls is exemplified in two buildings (one of three and one of two stories).

(*c*) The haunched beams and reinforced-concrete curtain walls in reinforced-concrete frame of a two-story building show the least effect of strain of any buildings in the town.

Foundations.—In general, spread footings tied together, continuous spread footings, or raft foundations are favoured in this locality. The spread footing is the usual form, the raft foundation being reserved for buildings with extensive basements. Each type has proved eminently satisfactory.

Basements suffered no damage beyond slight cracks in the floor.

Ground Floor.—It is evident that the heaviest stresses are concentrated in the ground-floor framing, and this, owing to extensive window and door areas, is usually the least rigid portion of the structure.

Little comparative data can be obtained relative to the respective merits of flexible and rigid ground-floor-frame construction. All the largest buildings, with their reinforced-concrete or brick curtain and partition walls, belong, in effect, to the rigid type.

The failure of two particular single-storied buildings appears to argue against the theory that flexibility of construction is a desideratum. Resonance is always to be feared, and then the alternating stresses on the columns, particularly just above floor-level and below beam-junction, tend to crush and disintegrate the concrete, permitting greater strain of each successive oscillation of the building. In one case the heavily reinforced bearing-walls, although still fairly sound, show evidence of heavy strain. The possibility of overstressing the steel in these circumstances appears by no means remote.

If it is not possible to brace each bay in a series of ground-floor shops or offices, then one or more symmetrically situated bays should be stiffened sufficiently to take the horizontal thrust. Alternatively, it may prove more economical to provide greater rigidity by strengthening columns, using haunched beams, or providing knee-bracing. It is inadvisable to provide rigid bracing of too local a nature in a building of any magnitude. Due consideration must be given to the type of adjoining buildings, and provision made for extra stresses likely to be incurred therefrom.

Columns.—In the three instances of failure of reinforced-concrete buildings the weakness has lain in the columns—one through faulty design and construction, and the other two through undue flexibility. Where steel columns and caps are used as interior and street-line supports the greatest caution must be observed in the provision of means to resist horizontal thrust. Particular attention must be paid to those portions of concrete columns directly above and below the points of restraint. Liberal use of hoops or bands at these sections and greater care in holding the steel in place in the forms are recommended.

Beams.—In spite of palpable errors of design and construction, in only one instance has there been any evidence of beam or girder failure. In fact, these members err more on the side of uneconomical strength and weight. Lack of bearing-area, eccentric bearing, and inadequate anchorage at wall-columns, &c., are the most patent defects.

Curtain Walls.—Four-inch curtain walls reinforced with $\frac{1}{4}$ in. rods horizontally and vertically at 12 in. to 18 in. centres have proved entirely satisfactory. The diagonal shear-cracks seen in brick curtain walls point to the economy of using less steel with diagonal reinforcement; but this saving would perhaps be offset by more expensive construction.

Fire-resistance.—The reinforced-concrete shell of one building with heavy concrete parapet walls survived the earthquake unscathed (basement and three floors). That the interior of this building was subjected to intense heat is indicated by the melted wire glass. No water was played on this fire. Where the concrete was dense the steel has been protected, and only the surface skin suffered; but wherever honeycomb formation is apparent the material is spalled, disintegrated, and severely damaged to a depth of 3 in. and more. This honeycomb formation is most pronounced at the junction of successive pours in the boxing. In another building the same weakness has developed in an incipient form in the columns, the fire aggravating the fault in the original construction.

GENERAL.

Elevated Tanks.—Tank-stands need heavy bracing. The tanks should be well tied to the stand, as the movement of the contained water has a heavy overturning moment. It is advisable to have the top completely open. Several fatalities resulted from the collapse of tanks.

The policy of incorporating tank-supports in a building-frame is objectionable for obvious reasons.

The horizontal ties of reinforced-concrete tank-stands serve primarily to reduce the unsupported length of column, and invariably show signs of severe strain unless used in combination with diagonal bracing.

The several local examples of small tanks on well-braced steel towers are all in sound condition.

Roads, &c.—On the local road system subsidence occurred at bridge-approaches, embankments, and culvert sites. On original ground no damage was sustained by the bitumen or concrete surfacing. Expansion joints in the latter type occur on an average at intervals of approximately 50 ft. In a number of instances incipient spalling and buckling is apparent in continuous kerbing and concrete footpaths.

Water-mains, &c.—The water-mains are of cast-iron pipe with lead-run joints, or spirally riveted pipe with bolted flange and rubber gasket. Apart from subsidence at bridges and at two recent fillings, no appreciable damage occurred to the system. Joints appear to be satisfactory.

The sewerage system is laid with concrete and glazed earthenware pipe at depths varying from a few feet to 12 ft. This, again, suffered no appreciable damage.

Conclusion.—Perhaps the most striking fact that impresses itself upon one's notice, in even a cursory examination of damaged structures in this area, is the evident inadequacy or total lack of competent supervision during construction. Omission of minor details in plans and departure from recognized standard practice in building-construction have resulted in serious and unnecessary damage. Proper adherence to the canons of sound construction, both as to workmanship and design, coupled with sane engineering judgment, would have averted the serious loss of life and considerably mitigated the structural damage.

In conclusion, it is recommended that, for all structures of a business, public, or industrial character, the plans and specifications be submitted for qualified checking and approval, and that it be insisted a competent clerk of works supervise the construction.

Efforts to arrive at a value of the accelerations in the earthquake have met with no success. The results have been too variable and untrustworthy. Relevant to this is the following extract from *Engineering News Record* of the 26th April, 1928, page 652: "The overturning of small structures such as stone monuments, by the earthquake has been utilized to compute the accelerations necessary for overthrow. The latter method of estimation is likely to result in errors of considerable amounts."

The case of a suspended electric light smashing against the ceiling gives a value of the period of the waves over a few seconds. The waves of the earthquake must have synchronized with the swing of the lamp for sufficient time to build up a wide movement. The lamp (repaired) made forty complete oscillations in one minute.

(NOTE.—This general report was based on a detailed analysis of the damage sustained by a large number of individual buildings. Full particulars of his detailed investigations, illustrated by photographs and plans, were forwarded to the Committee by Mr. Brodie.)

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