Pan American Health Organisation
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St Augustine, Trinidad
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Workshop on Mitigation Procedure for Medium-Sized Institutional Buildings

Documents Prepared
by
Tony Gibbs
Consulting Engineers Partnership Ltd
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Background Paper on the Conceptual Design of Buildings for Multiple Natural Hazards

Prepared and Assembled
by
Tony Gibbs
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Design for Multiple Hazards

Conceptual Design of Buildings to resist Wind and Earthquake Forces

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Tony Gibbs
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(Originally written for the PAHO/IDNDR
publication: "Mitigation" in 1991/2)

Design for Multiple Hazards
Conceptual Design of Buildings to Resist Wind & Earthquake Forces
Tony Gibbs

Conceptual design involves a series of decisions among which are:

(a) the geometry or shape or configuration of the building;
(b) the siting of the building;
(c) the materials of construction;
(d) the structural system.

So basic are these issues that they must be addressed at the earliest stages in the development of a project. All parties should be involved at this stage - client, architect, engineers, constructors. The present organisation of the building industry makes it difficult for constructors to be involved in design development. This is a pity. However, this places a greater obligation on architects and engineers to understand the construction process better, to understand the implications of their design decisions on costs and facility of construction. Costs are affected by relative ease of construction; availability of materials, equipment and labour; time for construction. In some societies the responsibility for monitoring costs is given to a separate discipline - the quantity surveyor. It would be better if the knowledge of costs resided in the minds of the designers. To take this argument to its logical conclusion, it would be better if one person (the conceptual designer) had facility in architecture, engineering, cost estimating and construction. Such a person used to be the Master Builder.

> Civilization is built on Specialization. Specialization may destroy Civilization."
> - Arup.

When engineers become involved in "design", they take out their calculators too quickly. True design precedes detailed calculation. To be sure, some calculation is required in the process of design, but the principal calculations can only be done after the bulk of the design has been done Mathematics is then a tool for refining the design and for determining the details of construction. This is not to downplay the importance of structural analysis and detailing. It is to emphasize the proper chronology of these functions. The life cycle is as follows:

(1) Design (ie conceptual design)
(2) Analysis
(3) Detailing
(4) Construction
(5) Maintenance
(6) Demolition.

Each function is affected by each other stage in the cycle, but this is not at variance with the order of precedence given above. Good analysis cannot make up completely for bad design, and good construction can certainly not correct bad detailing.

Designing against multiple hazards is more than doubly difficult, especially when those hazards are wind and earthquake. Many favourable features of wind-resistant design are unfavourable for earthquake-resistant design and vice versa.

(a) Heavy structures resist winds better. Light structures resist earthquakes better.

(b) Flexible structures attract greater wind forces. Stiff structures (generally) attract greater earthquake forces.

Both hurricanes and earthquakes impose horizontal loads on buildings. Earthquakes also impose significant vertical loads on a building overall. The vertical loading derived from wind is usually significant on parts of a building as determined by aerodynamic considerations.

However, there are many similarities in the effective design and construction of buildings to resist hurricanes and earthquakes:

(a) Symmetrical shapes are favourable.

(b) Compact shapes are favourable

(c) There must be a realization that there is a real risk that "design" forces may be exceeded. This is particularly so in the case of earthquakes where the design force is deliberately determined to be less than that expected during the anticipated life of the building. This leads to a requirement for redundancy in the structure and for "toughness" - the ability to absorb overloads without collapse.

(d) Connections are of paramount importance. Each critical element must be firmly connected to the adjacent elements.

There is a basic difference in the performance expectations in the event of an earthquake as opposed to a hurricane. A building is expected to survive its "design hurricane" with virtually no damage. Even a catastrophic hurricane should only lead to repairable damage. On the other hand the "design earthquake" is expected to cause (hopefully repairable) damage, and a catastrophic earthquake is likely to lead to a situation where the building cannot be repaired and must be demolished. In such an event success is measured by the absence of deaths and serious injuries.

The accompanying table summarizes the main differences between hurricanes and earthquakes as they affect structural design.

	Wind	Earthquake Effects
(1) Source of loading	External force due to wind pressure	Applied movements from ground vibration
(2) Type and duration of loading	Wind storm of several hours' duration; loads fluctuate, but predominantly in one direction	Transient cyclic loads of at most a few minutes' duration; loads change direction repeatedly
(3) Predictability of loads	Usually good, by extrapolation from records or by analysis of site and wind patterns	Poor; little statistical certainty of magnitude of vibrations or their effects
(4) Influence of local soil conditions on response	Unimportant	Can be important
(5) Main factors affecting building response	External shape and size of building; dynamic properties unimportant except for very slender structures	Response governed by building dynamic properties: fundamental period, damping and mass
(6) Normal design basis for maximum credible event	Elastic response required	Inelastic response permitted, but ductility must be provided; design is for a small fraction of the loads corresponding to elastic response
(7) Design of non-structural elements	Loading confined to external cladding	Entire building contents shaken and must be designed appropriately

Main differences between wind and earthquakes

From The Arup Journal

The extensive loss of life and property caused by hurricanes and earthquakes can be avoided by the implementation of existing technology and without great financial strain. What is required is the will to do so. Because it would require about two generations to replace the building stock in most communities, as much attention should be paid to the retrofitting of existing buildings as to the improved design and construction of new buildings. At this time there are few technical constraints governing the design and construction of most buildings against hurricanes and earthquakes. (This is not to say that research and development should not continue.) However, there are severe cultural, socio-economic, political and bureaucratic constraints to achieving success in this field.

Education and training programmes need to have a greater emphasis placed on the specific requirements of earthquake-resistant and hurricane-resistant design. At the higher educational levels the subjects should be taught from the points of view of background studies and fundamentals. The mere teaching of code procedures is not enough.

The lack of code enactment is a serious hindrance to progress in many territories. Of course code enactment would not be enough without enforcement. Funding agencies (loans and grants), domestic mortgage institutions and insurance companies could play pivotal roles in this regard.

Structural configuration is the single most important factor in determining the performance of buildings subjected to earthquakes and hurricanes. The following recommendations are proposed and are particularly appropriate for non-engineered construction and for minimum-cost construction:

(1) Limit the height of buildings to one and two storeys.

(2) Use lightweight floors and roofs to reduce risks in earthquakes. But ensure that they are securely fastened to the walls to improve their performance in hurricanes. Alternatively, if concrete roofs are used as a hurricane-resistant strategy, ensure that the vertical elements (walls and columns) are conservatively built to carry the significant horizontal loads from earthquakes.

(3) The shape of the building should be, as far as possible, symmetrical. This symmetry also applies to the arrangement of partitions and openings. This would lead to a more balanced distribution of forces in the structure.

(4) Provide sufficient distance between openings to avoid slender piers. Keep the openings moderate in width to avoid long-span lintels.

(5) Link the heads of all walls together by providing a continuous collar or ring beam at floor and roof levels.

(6) Lightweight roofs should be not less steep than 20 degrees (generally speaking, the steeper the better up to about 40 degrees) to improve their wind resistance.

(7) To improve their wind resistance lightweight roofs should have a hipped shape (sloping in four directions) rather than a gable shape (sloping in two directions) or a monopitch shape.

(8) Again, to improve their wind resistance, lightweight roofs should have minimum overhangs at the eaves. In fact it would be better to have no overhangs and to introduce a parapet. The need to shade windows and doors from sun and rain may be met by separate canopies.

(9) The incorporation of ridge ventilators would reduce internal pressures and help keep on lightweight roofs in a hurricane.

Clearly, the above recommendations are very restrictive indeed. But to vary significantly from them would require the conscious involvement of engineers to achieve safe construction. Today's technology permits almost anything to be done. In fact, it could be said that advances in technology are responsible for much bad design. Technology (and money) permits badly designed buildings to be made safe. The aim is not to restrict design but to sensitize people to those factors requiring caution.

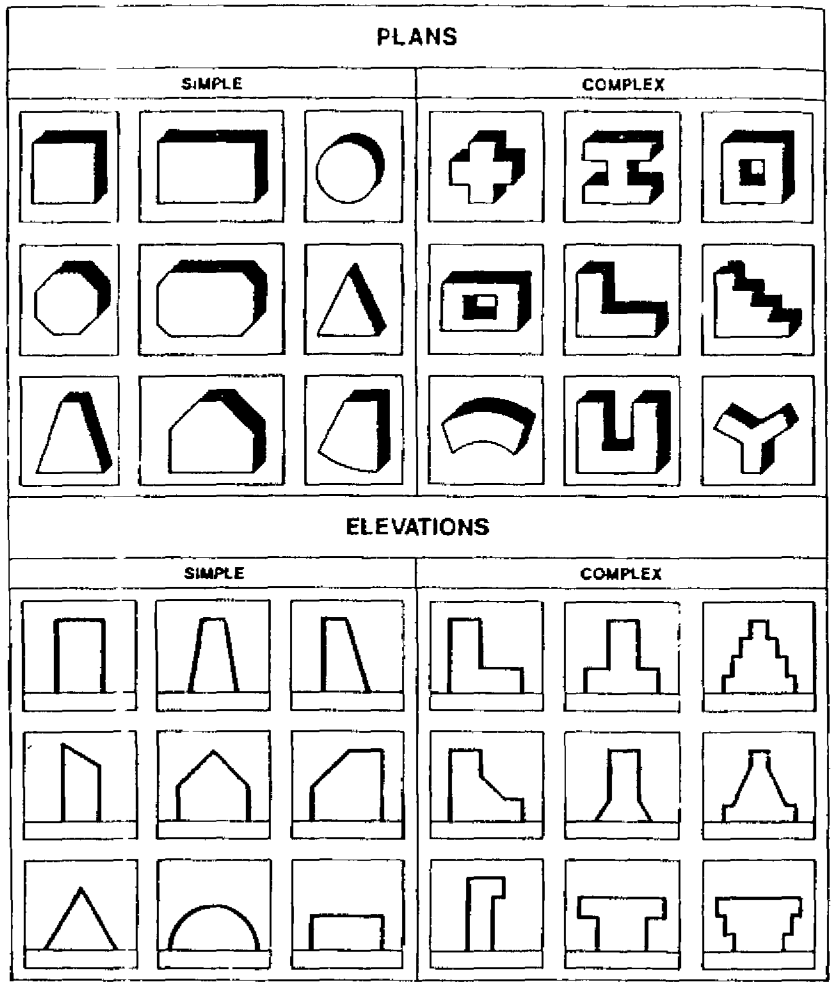
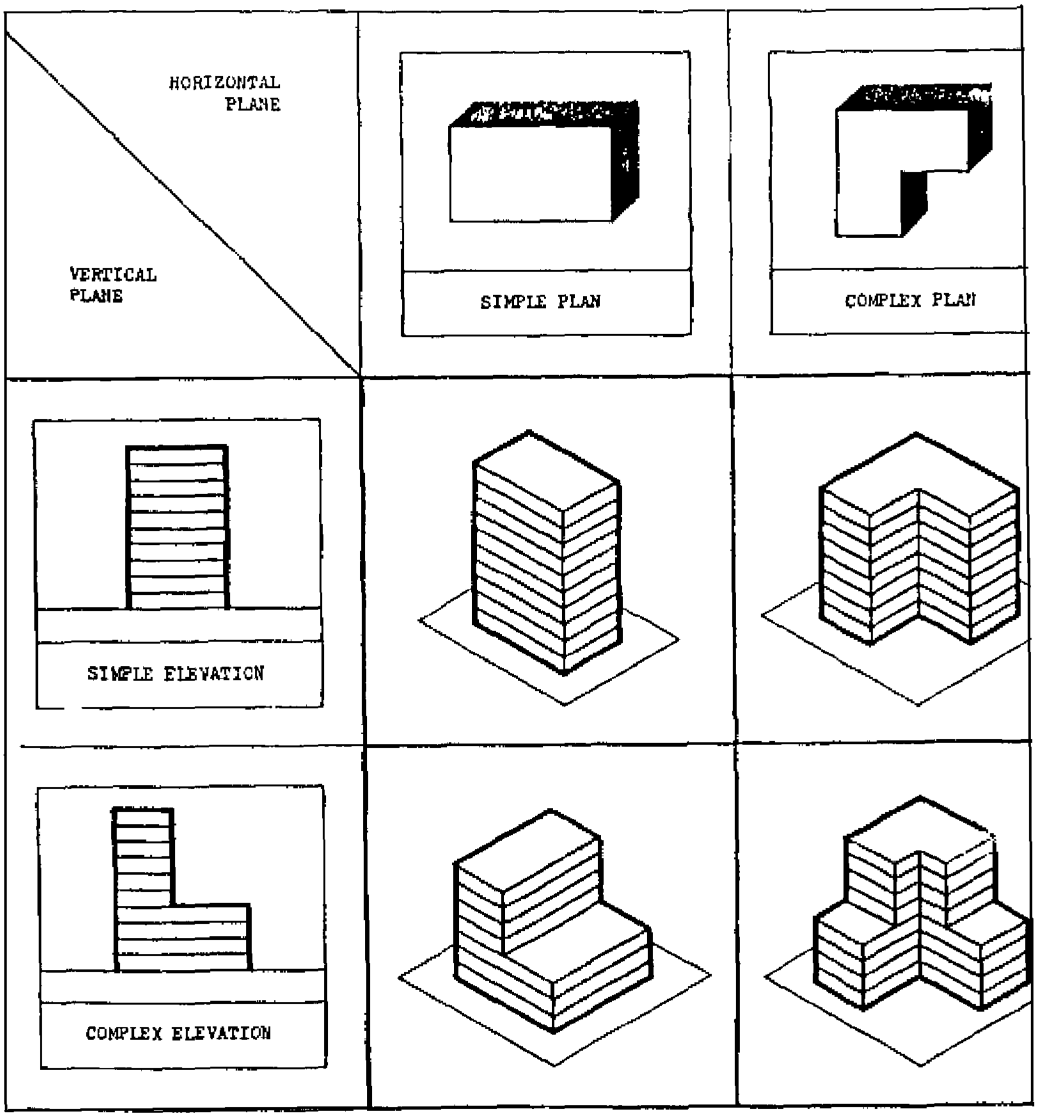
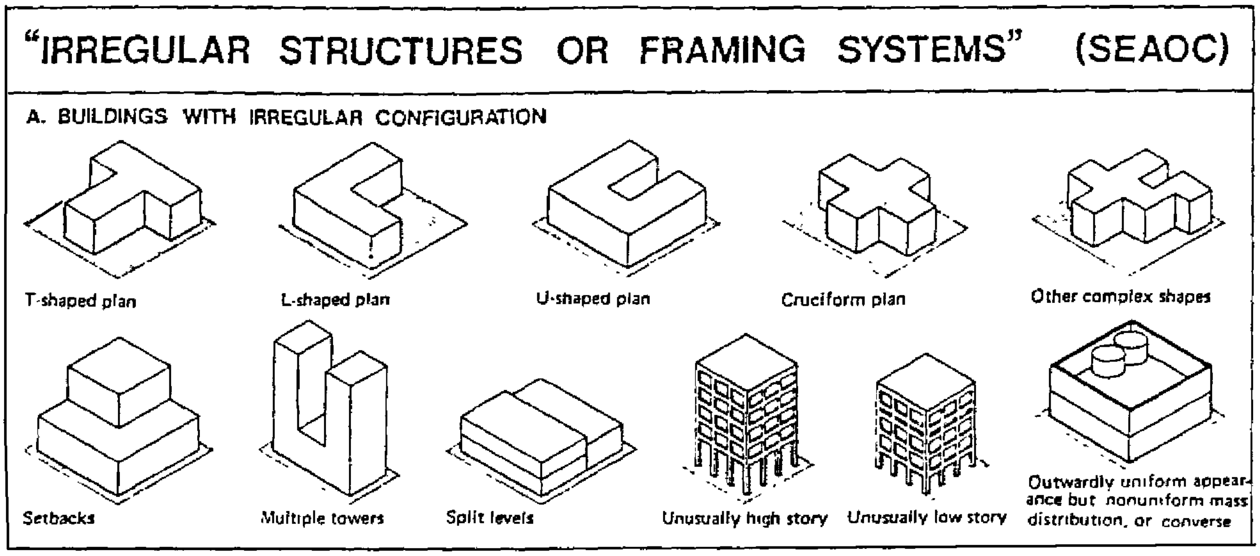
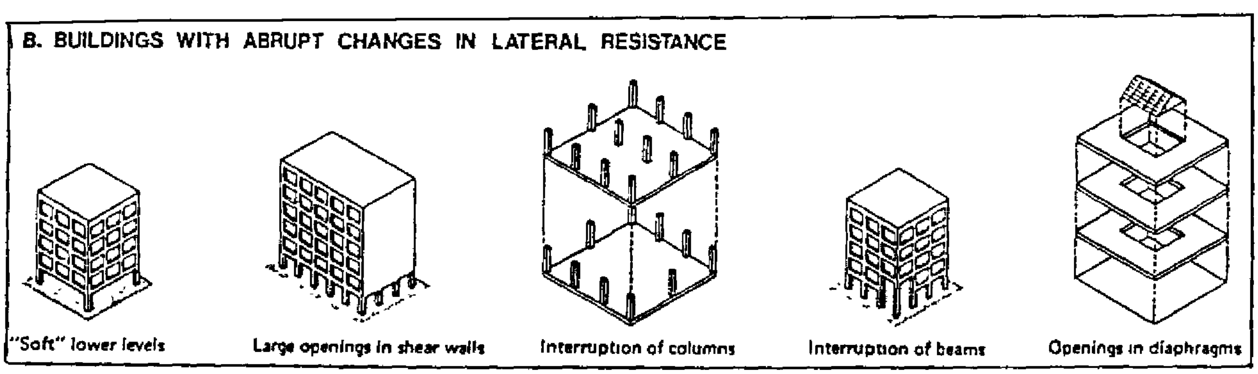


Figure A3-2 Simple and complex shapes in plan and elevation

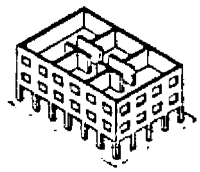
MATRIX OF BUILDING SHAPES



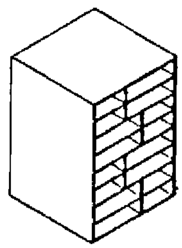

"IRREGULAR STRUCTURES OR FRAMING SYSTEMS" (SEAOC)
A. BUILDINGS WITH IRREGULAR CONFIGURATION
T-shaped plan
L-shaped plan
U-shaped plan
Cruciform plan
Other complex shapes
Setbacks
Multiple towers
Split levels
Unusually high story
Unusually low story
Outwardly uniform appearance but nonuniform mass distribution, or converse


B. BUILDINGS WITH ABRUPT CHANGES IN LATERAL RESISTANCE
"Soft" lower levels
Large openings in shear walls
Interruption of columns
Interruption of beams
Openings in diaphragms

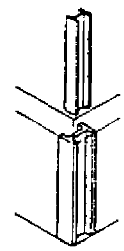
C. BUILDINGS WITH ABRUPT CHANGES IN LATERAL STIFFNESS



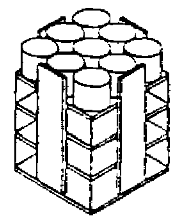
Shear walls in some stories,
moment resisting frames in others



Interruption of vertical-resisting elements



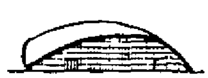
Abrupt changes in size of members



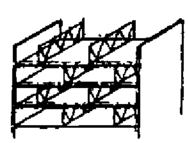
Drastic changes in
mass/stiffness ratio

D. UNUSUAL OR NOVEL STRUCTURAL FEATURES

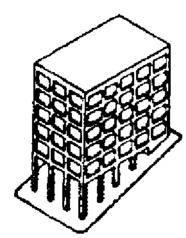
Cable-supported structures



Shells



Staggered trusses



Buildings on hillsides

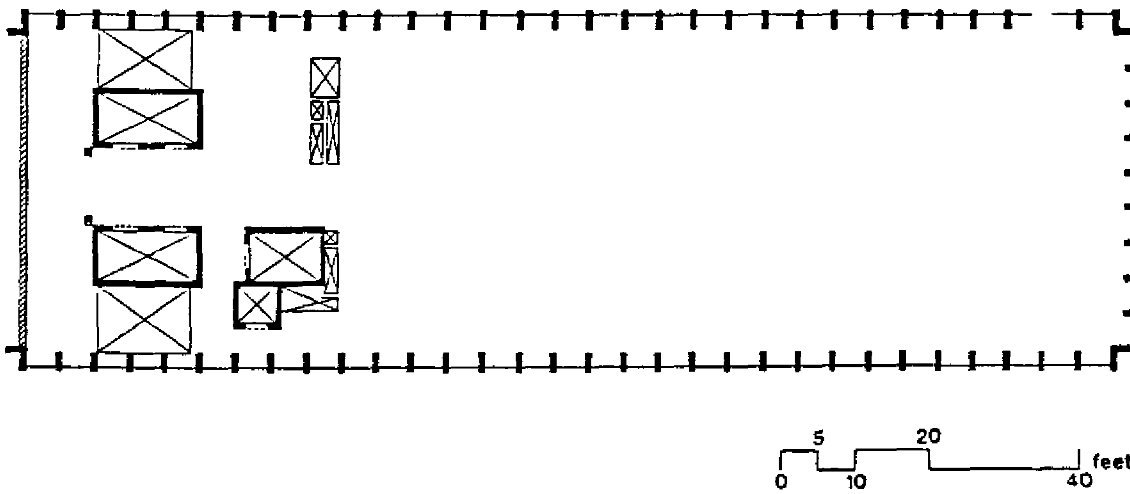
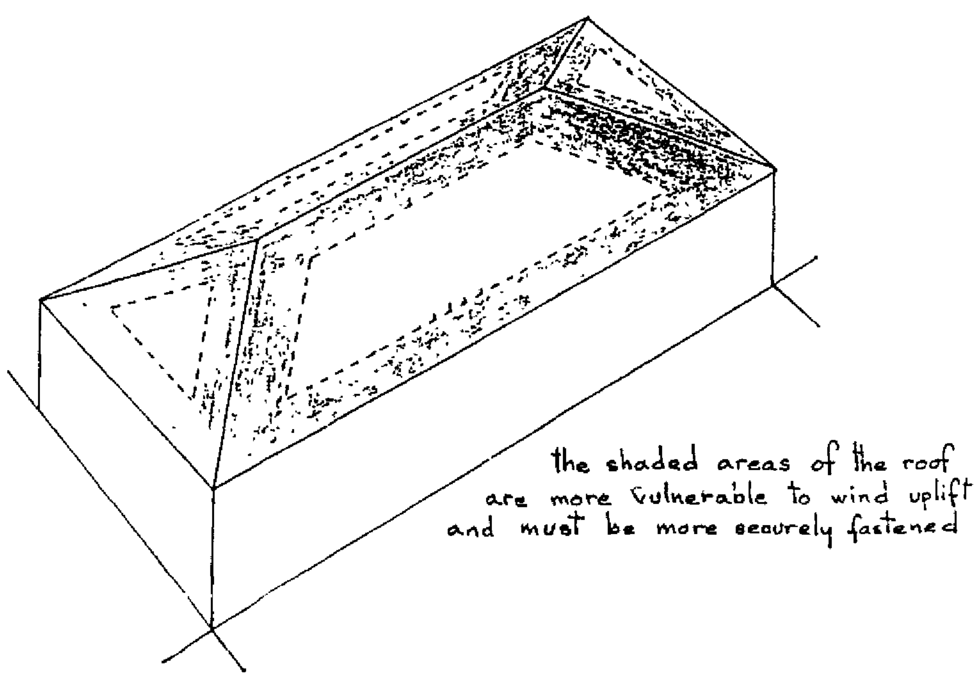


Figure 4-21. False symmetry: Banco Central, Managua, Nicaragua. [Redrawn, with permission, from John F. Meehan et al., "Engineering Aspects," in *Managua, Nicaragua Earthquake of December 23, 1972, Reconnaissance Report* (Oakland, California: Earthquake Engineering Research Institute, 1973).]



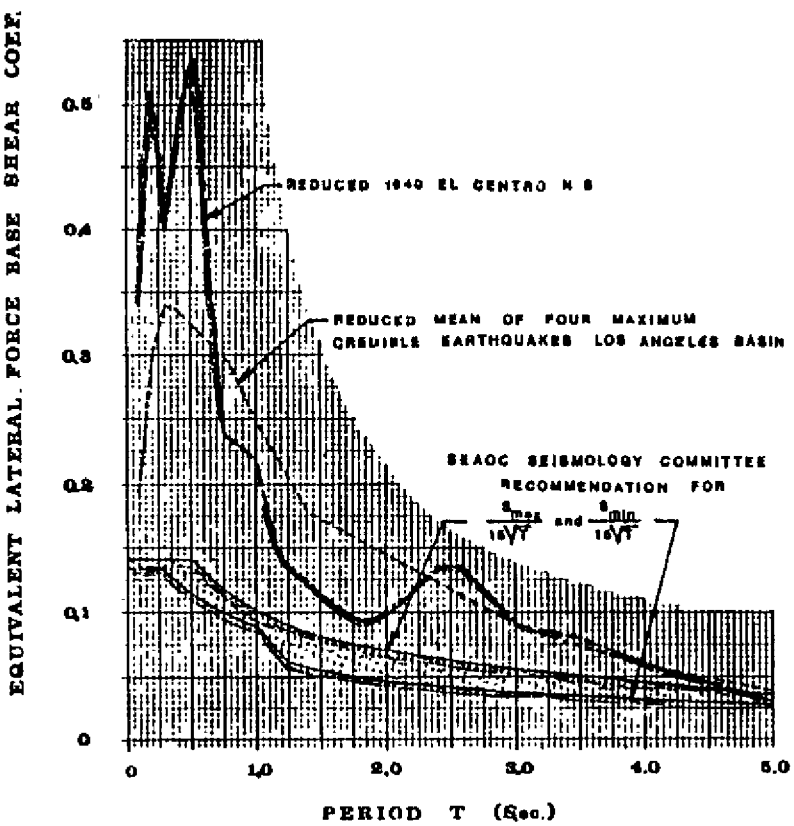


FIG. 1D-3 BASE SHEAR COEFFICIENT

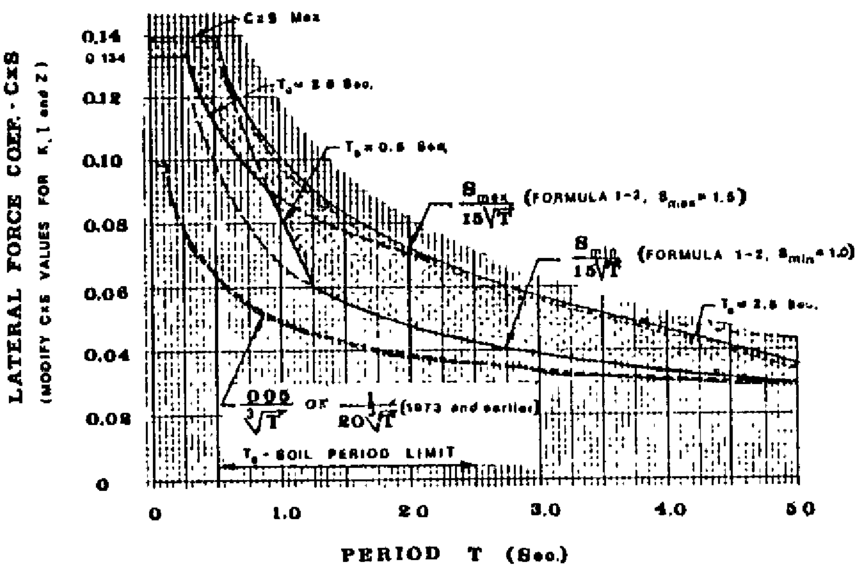


FIG.1D-4 LATERAL FORCE COEFFICIENT

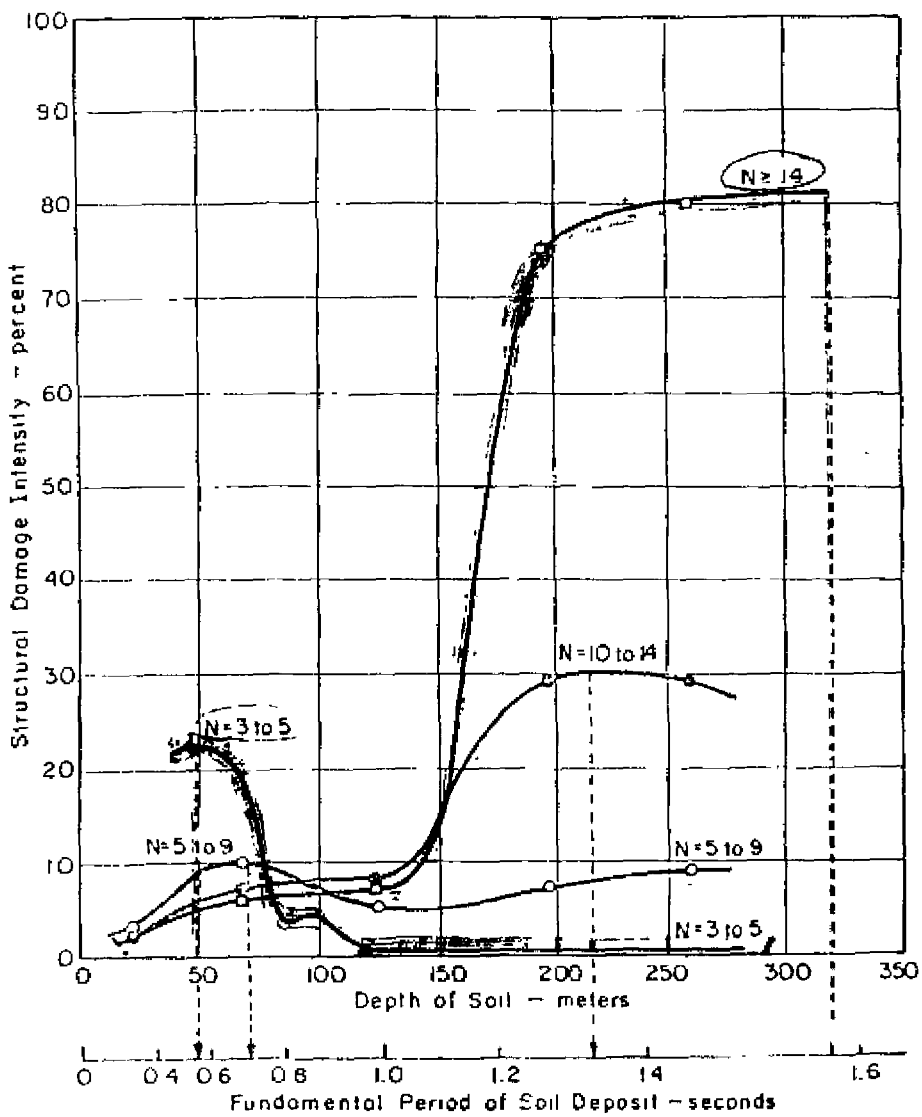


FIG 5 RELATIONSHIP BETWEEN STRUCTURAL DAMAGE INTENSITIE AND COMPUTED FUNDAMENTAL PERIODS OF SOIL DEPOSITS

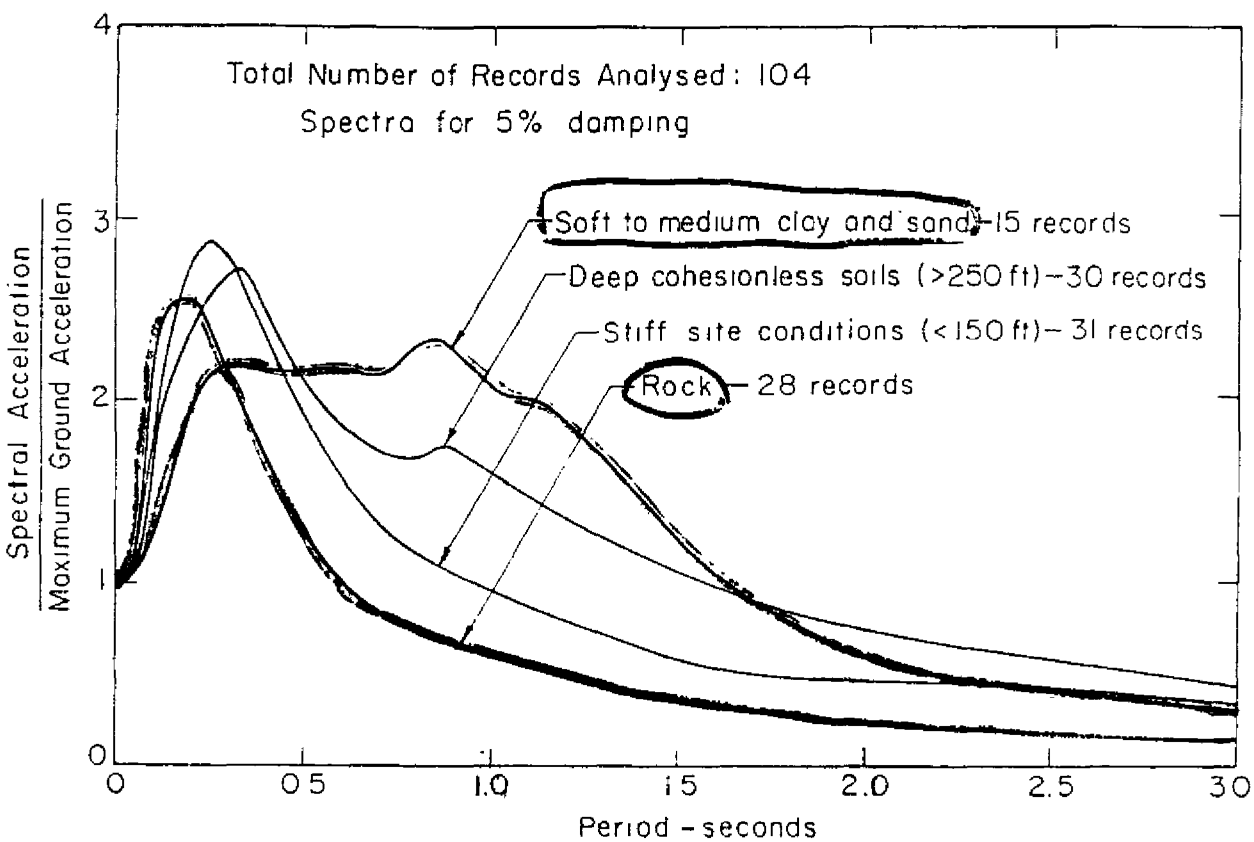


Fig 7 AVERAGE ACCELERATION SPECTRA FOR DIFFERENT SITE CONDITIONS

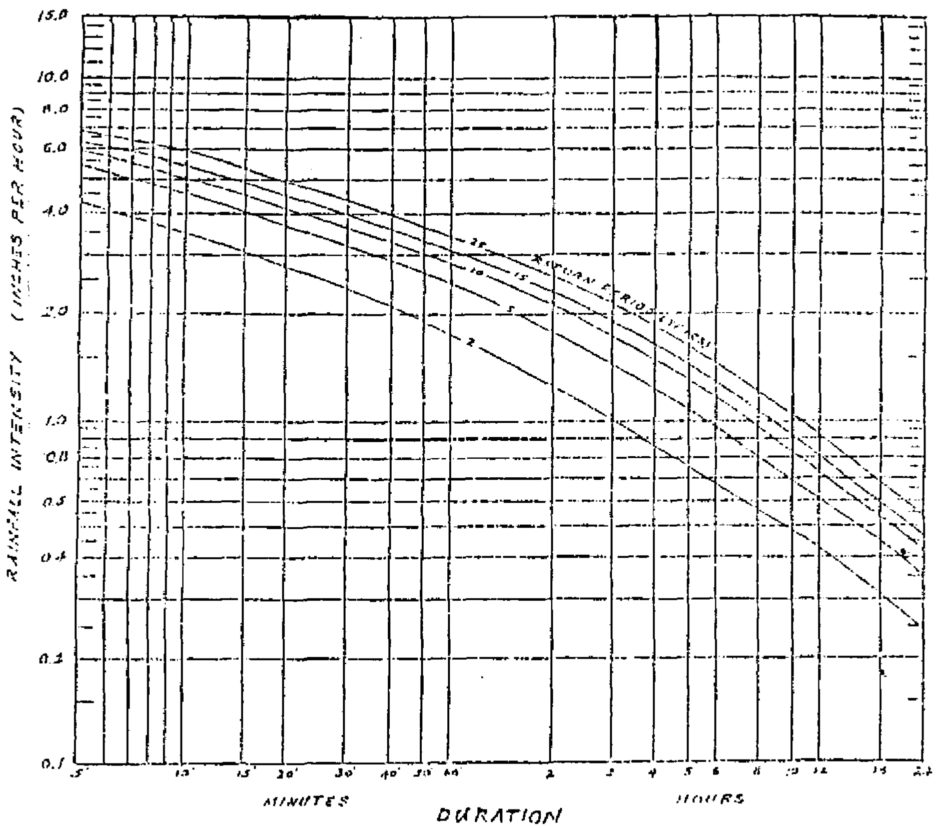


Figure 9

RAINFALL INTENSITY-DURATION-FREQUENCY CURVES

C.M.I., HUSBANDS (S 5)

Period: 1969 - 1970

Elevation: 370 feet above MSL

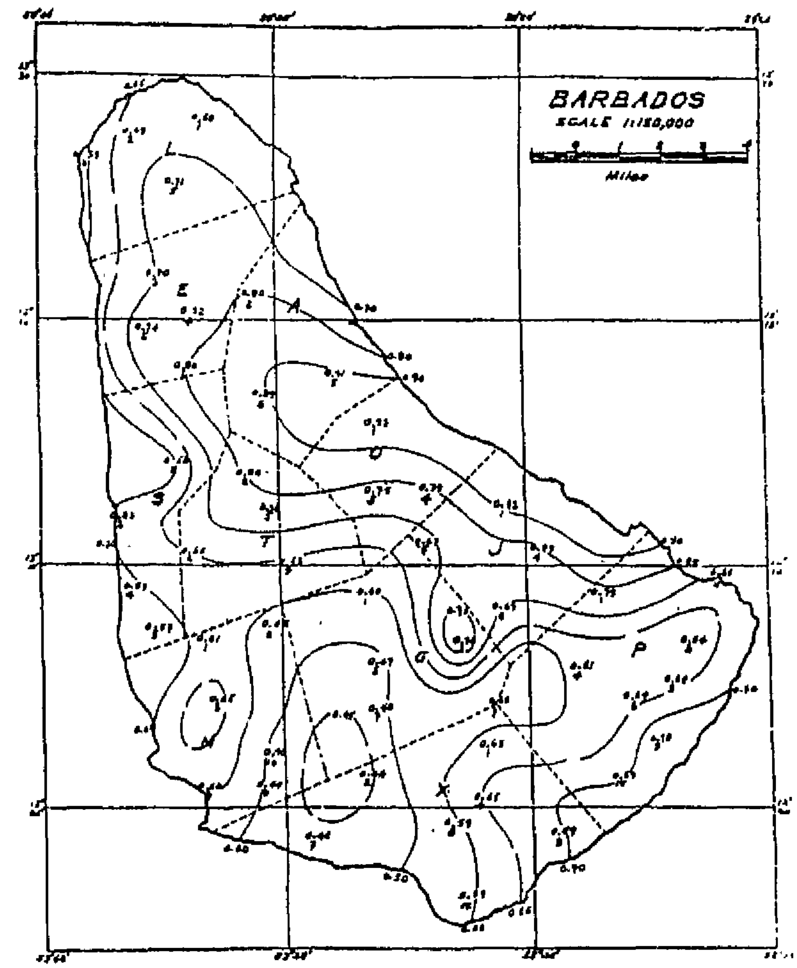
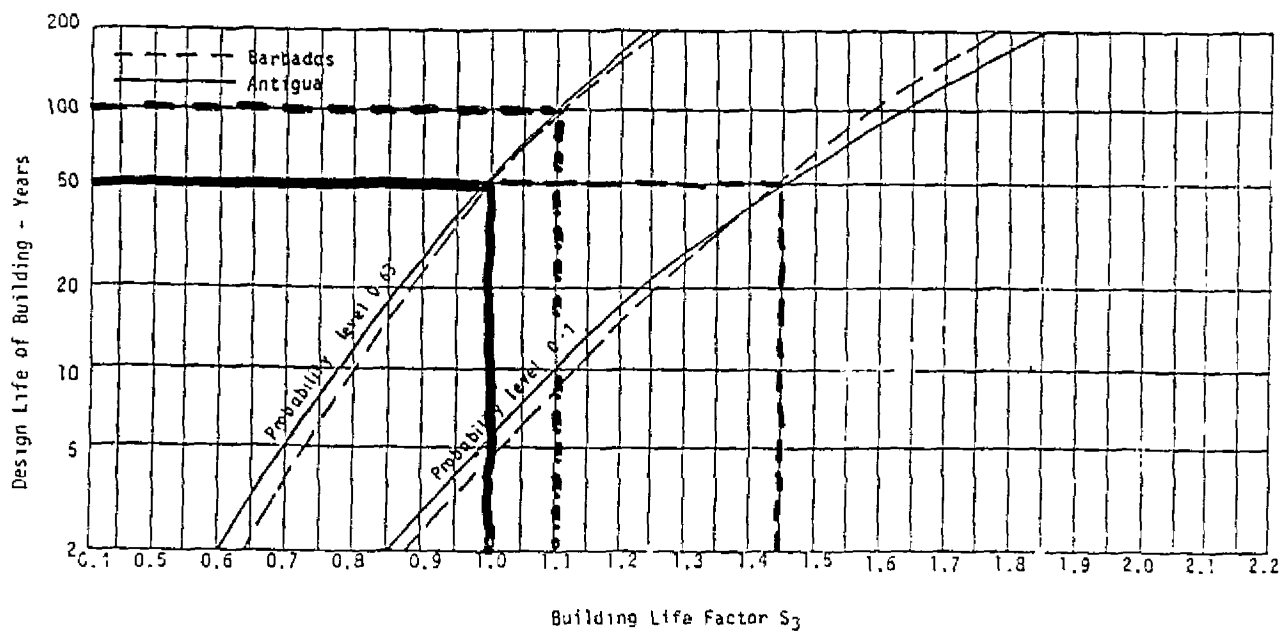


Figure 2.6 Rainfall Isohyets for Barbados

Category	Wind Speed (Fastest Mile)		Damage
	km/hr	mph	
HC1	119 - 151	74 - 95	Minimal
HC2	152 - 176	96 - 110	Moderate
HC3	177 - 209	111 - 130	Extensive
HC4	210 - 248	131 - 155	Extreme
HC5	>248	>155	Catastrophic

FIGURE 1 - FACTOR FOR BUILDING LIFE



Averaging Period	Wind Speed			
1 hour (Canada)	120	113	91	79
10 minutes (CUBiC)	127	120	96	84
Fastest mile (USA)	158	149	120	105
3 second (BAPE)	181	171	137	120

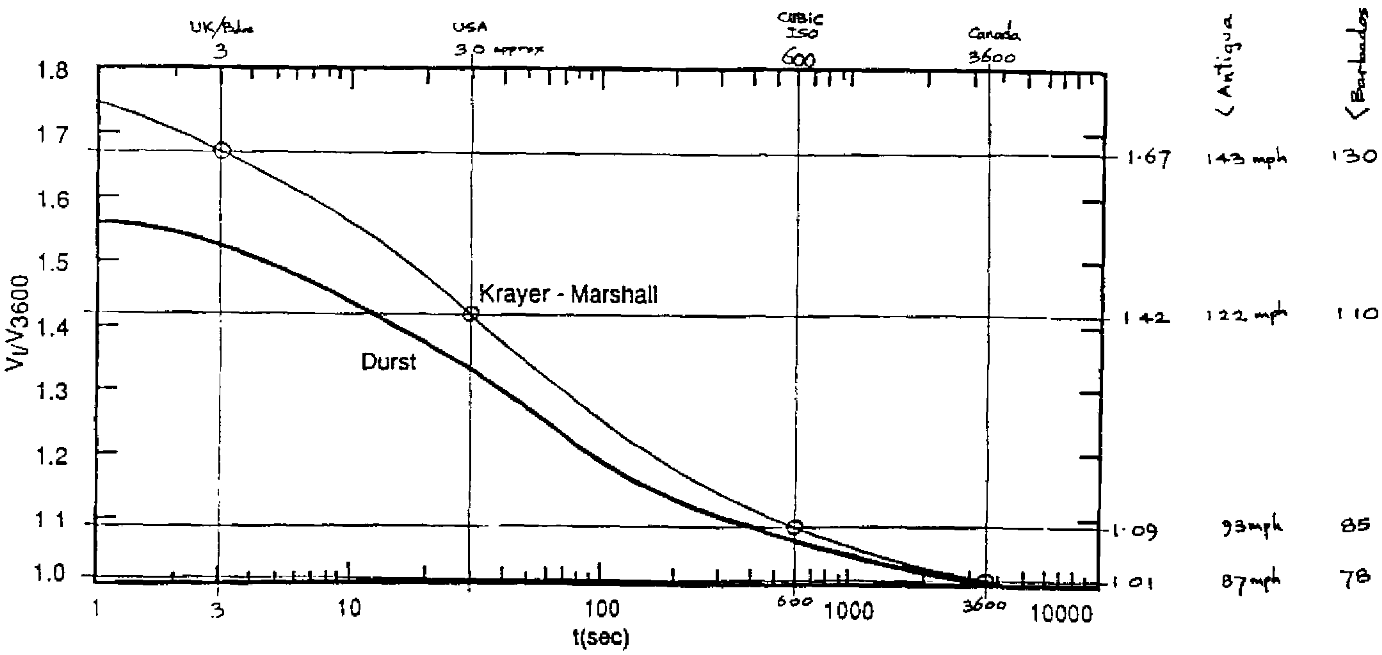
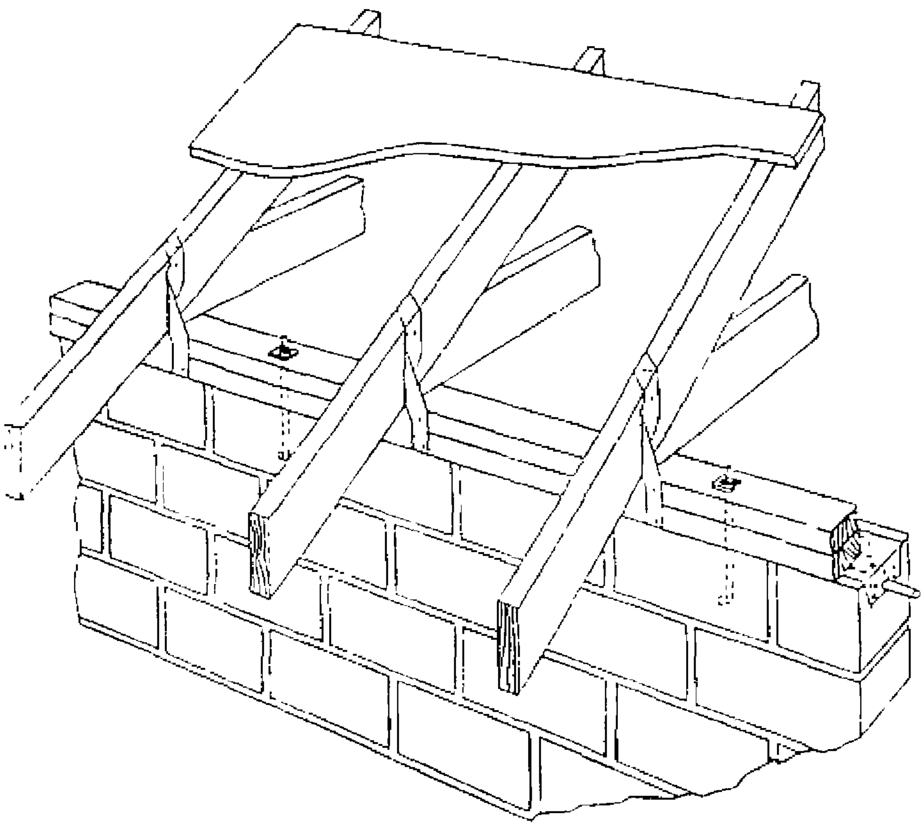


Fig. 2.1 Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

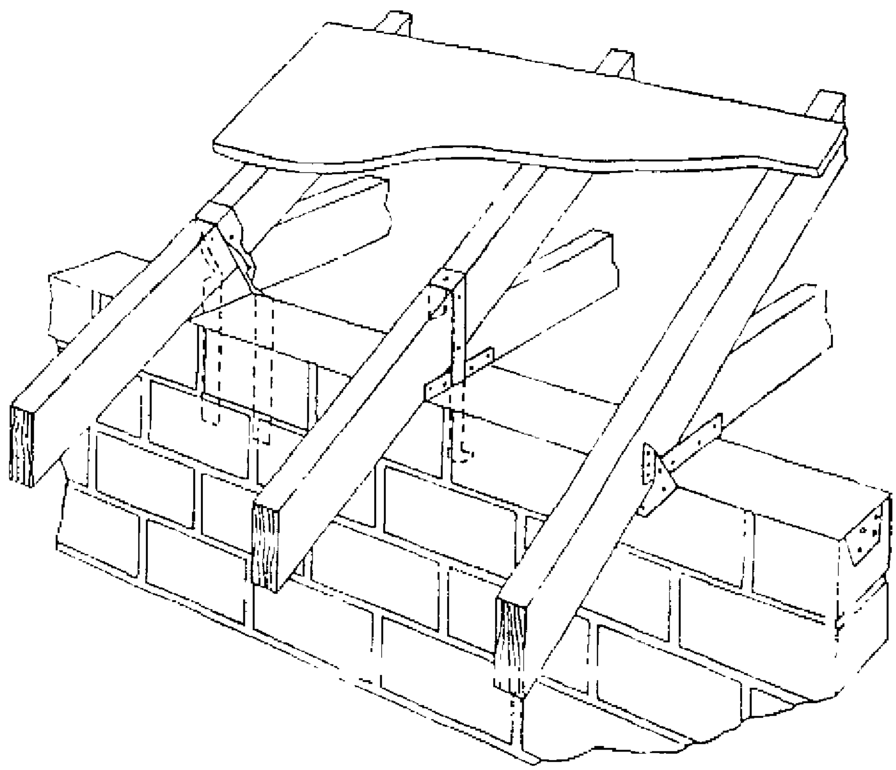
Source: Ref. 4

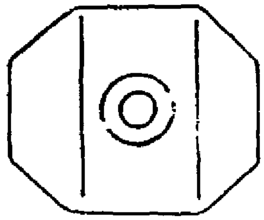
ROOF TO MASONRY WALL CONNECTION
BOLTED TOP PLATE ALTERNATE

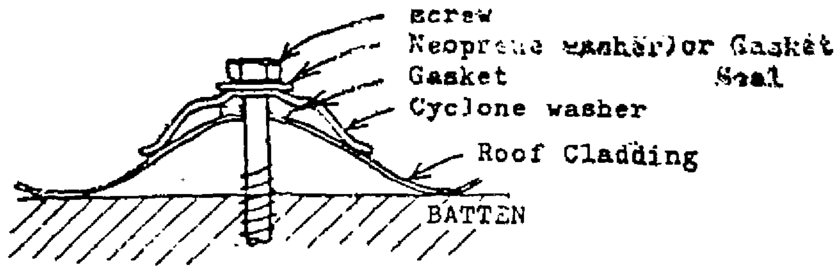


ROOF TO MASONRY WALL CONNECTION
DIRECT TO BOND BEAM

Per manufacturer's recommendation: Two outside connectors attached to bond beam with concrete screws. Middle connector embedded in bond beam.







Screw Fixing : Example of Use of One Type of Cladding Fixing Specified by a Manufacturer for use of a Particular Product in Cyclonic Areas

Cyclone Washer : Example of One Type Specified by Manufacturers

ALSO SPECIFIED :
- Spacing of fixings
- Increased fixing at roof edges and changes in slope
- Special requirements (eg holes through sheet to be predrilled
  screws not to be overtightened
  etcetera)

FIG. 11 : EXAMPLE OF FIXING FOR SHEET METAL PRODUCT
(Exact Requirements Given by Manufacturer)

Accessories for Fixing all Profils.

X - ACCESSOIRES DE FIXATION POUR TOUS LES PROFILS