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CONSTRUCTION PRACTICES AND SEISMIC VULNERABILITY: TYPICAL SINGLE-FAMILY DWELLINGS IN TRINIDAD, WEST INDIES

by

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ABSTRACT

The paper examines the prevailing patterns of design and construction in a sampling of the more common single-family middle-income residential structures in Trinidad, West Indies. Factors of concern include the following:

> Many houses are on alluvial soils, and are therefore susceptible to possible site-amplification phenomena.

> Houses are usually "designed" and constructed with no inputs from professional engineers or construction technicians; draughtsmen often produce "designs" for substantial two-storey houses without assistance.

> There is general absence of structural components necessary to provide adequate lateral-force capability.

> Connection details are often grossly deficient, and entire topmost storeys are often built with no vertical reinforcement whatsoever.

The paper provides an initial assessment of the sensitivity of such structures to lateral seismic loadings in particular, and identifies features which should be avoided in such buildings in the future. Prevailing soil types, the regulatory framework of housing approvals, and other pertinent factors are also briefly addressed in the paper.

BACKGROUND

Most of the population of approximately 1.15 million persons in the island of Trinidad live in single-family dwellings. Most of those dwellings have not been designed by professional engineers; most have been constructed with supervisory inputs from engineering or building technicians; most of the builders of these houses have not been trained in the basics of building materials and practices; some were the homeowners themselves.

The islands of Trinidad and Tobago are in a seismically active zone; opinion has been divided regarding the seismic zoning of Trinidad, but the island is generally agreed to lie in SEAOC zones 3 and/or 4.

SCOPE OF THE PAPER

The paper is limited to an initial assessment of a sampling of "typical" middle-income single-family houses in Trinidad* as regards:

Structural layout

Materials selection and usage

Prevailing building practices

and therefore, as regards their resulting seismic vulnerability. By definition, no data related to apartment or condominium housing is presented; also, no assessment of single-unit mass housing is included; some are known to be little better designed and constructed than the individually built housing units which are the focus of this paper.

MOTIVATION

The issue of "what would happen to Trinidad housing if a good-sized earthquake hit" has been debated by engineers for many years; the author is however unaware of any published data setting forth an assessment of the vulnerability of such housing. The following facts are pertinent:

* Data for Tobago was not accessible within the resources available for the preparation of the paper

Many houses are founded on clayey soils, and are therefore subject to amplification effects during seismic events.

Many houses are of empty (soft) ground storeys, made up of reinforced concrete columns supporting a solid reinforced concrete slab on which is built an effective bungalow of unreinforced hollow-block masonry walls with a timber-framed roof, in effect an inverted pendulum type of arrangement.

There are no regulatory requirements which require structural checks to be made of the plans of single-family houses which are submitted for approval for building.

Even if plans were to be structurally sound, the enforcement of proper construction/building procedures and details is typically left up to the individual small builders themselves; these are often unapprenticed and untrained, and are often unaware of what constitutes "acceptable good practice" in the areas of concrete materials and practices, and reinforcement detailing.

External and internal walls are predominantly constructed with (plastered) hollow clay blocks, with a nominal wall thickness of 100 mm. As laid, the cores of these blocks are typically horizontal*, and therefore are usually left unreinforced. When hollow concrete blocks (the somewhat less common choice) are used, the vertical cores in the 100-mm size which is most common are insufficiently wide to make reinforcing a practical proposition, so that these are also left unreinforced in almost every case.

In the light of factors such as the above, it was felt that a start should be made to define, at least indicatively, the prevalent details and provisions in such housing. Subsequent activity should include:

(i) A more extensive and in-depth field survey of a larger sampling of the local housing stock.

(ii) The proposing of practicable and affordable retrofitting procedures to enhance the seismic resistance of the major types of existing housing.

* One manufacturer has very recently introduced a hollow clay block with vertical cores.

THE APPROACH TO THE ACQUISITION OF DATA

Field Survey of Houses under Construction

A field survey of houses being built (i.e. when their construction details would be visible) was carried out during June-September 1993. A copy of the survey form is attached as Appendix 1. The intention was to examine member and connection details relevant to the development and resistance of seismically-induced forces in the houses examined. It was also intended to sample any site-made concrete so as to carry out laboratory testing for compressive strength. This proved to be unworkable (as were attempts to obtain non-destructive test data from existing concrete columns); laboratory preparation of concretes of a range of mix proportions typical of field mixes was therefore carried out, and moulded cube specimens made and cured under conditions typical of "better" housebuilding sites. The compression specimens were then tested for compressive strength at 7 and at 28 days; the results are summarised in Table 1.

Table 1

Mix Proportions, Workability and Cube Compressive Strengths of Field-Simulation Concrete Mixes

Mix Code	Volume Proportions (measured loose)			Equivalent Ratios by Weight (measured)		Workability (estimated)*	Cube Compressive Strength* (MPA)	
	Cement:Fine:Coarse			W/C	A/C		7 day	28 day
SVR1	1	1½	3	0.65	6.2	"Firm"	31.2	42.8++
SVR2	1	1½	3	0.90	6.2	"Soupy"	13.8	20.6++
SVR3	1	2	4	0.85	8.0	"Medium"	18.9	25.3
SVR4	1	2	4	1.12	8.0	"Soupy"	11.8	17.2
SVR5	1	3	6	1.05	11.3	"Medium"	14.0	19.9
SVR6	1	3	6	1.30	11.3	"Soupy"	9.4	14.2

* "Firm": 0 - 50 mm slump; "Medium": 50 - 100 mm slump; "Soupy": Collapse

\+ Mean of three 100-mm test cubes

++ 32 day strength

SUMMARY OF THE FINDINGS OF THE SAMPLE SURVEY

Concrete columns (structural steel columns are not much used in domestic housing) supporting upper floors are usually 250 mm to 300 mm square.

These columns are typically of site-made concrete, mixed by hand, measured by volume, and water added to bring the mixture to between a medium-high (say 100-mm slump) and a "collapse" (> 150 mm slump) workability. Based on the experimental data in Table 1, such concretes may be expected to achieve 28-day cube strengths up to as much as 25 MPa, but the "soupy" (over-wet) concretes are unlikely to achieve beyond 17 MPa. Poor concrete quality has been identified as a contributor to column failure in many earthquakes.

Both mild steel (m.s.) plain round bars or high-tensile (H.T.) deformed bars are used for main (longitudinal) reinforcement in columns; sizes range from 12 mm to 20 mm diameter; typically 4 bars are used per column. With a yield stress factor of about 1.7 (HT/ms), main-reinforcement strength in columns can vary by a factor of approximately 4.7 (20-mm HT bars ÷ 12-mm m.s. bars).

Transverse bars (links; locally called "stirrups") in columns are generally inadequate, usually 6 mm, less frequently 10 mm diameter m.s. bars at 200 to 250 mm centres apart vertically. Either in terms of containment of longitudinal reinforcement under high compressive loadings, or in terms of shear capacity of sections, such provisions are insufficient. There are typically no extra links at floor and roof levels or at other zones of force transfer. Both the strength and the ductility of typical columns are unlikely to be satisfactory under significant seismic loadings.

The strength of concrete, and the anchorage of reinforcement, is often degraded by poor compaction of concrete in the field, as evidenced by substantial honeycombing, particularly at beam-column joints.

Unreinforced hollow clay or concrete block walls are held to their base slabs by mortar bond only; such walls have no post-cracking strength, and except for component interaction, can be expected to exhibit early and major damage in earthquakes. The connection details between intersecting walls are often indifferently executed; long runs of unbraced hollow-block walls, weakened by door and window openings, are sometimes found near living rooms (typically the largest room in the house). Entire storeys are put at risk by such details.

Many items of ancillary equipment, e.g. overhead water tanks and their stands, are unbraced and are susceptible to overturning failure under horizontal ground motions. With a 2000-litre water tank weighing in excess of one tonne when filled, the toppling of such elevated items could cause life-threatening damage to adjacent structures.

Many facades above verandahs are supported on "columns" which are made of vertical stacks of single hollow clay blocks; these can literally be demolished by a human blow (e.g. a kick) and are extremely fragile and dangerous.

CONCLUSIONS

Many features typical of the "design" and construction practices used in domestic housing in Trinidad, West Indies render such structures very vulnerable to seismic loadings. Whereas training and education, the enforcement of codes and standards and other such activities can provide for better-constructed dwellings in the future, the majority of the single-family housing stock remains vulnerable. Urgent efforts are needed towards the identification and implementation of practicable, affordable, and effective retrofitting of existing housing, in which large sections of the population continue to remain at risk. The seismic zoning of Trinidad reflects an awareness of the risk of a major occurrence, which is likely to result in a disaster of national proportions.

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