Construction Practices and Seismic Vulnerability: Typical Single-family Dwellings in Trinidad, West Indies

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Abstract

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

a) Many houses are on alluvial soil , and are, therefore, susceptible to possible site-amplification phenomena.
b) 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.
c) There is a general absence of structural components necessary to adequate lateral-force capability.
d) Connection details are often grossly deficient, and entire topmost storeys are often built with no vertical reinforcement whatsoever.

This 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 building 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, but 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, and 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 sample of "typical" middle-income single-family houses in Trinidad (data for Tobago was not accessible within the resources available for preparation of the paper) as regards structural layouts, materials selection and usage, and prevailing building practices and, therefore, 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:

(i) Many houses are founded on clayey soils, and are, therefore, subject to amplification effects during seismic events.
(ii) 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.
(iii) 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.
(iv) 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 who 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.
(v) 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 (one manufacturer has very recently introduced a hollow clay block with vertical cores) 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 qualitatively, 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 practical and affordable retrofitting procedures to enhance the seismic resistance of the major types of existing housing.

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" housebuildng sites. The compression specimens were then tested for compressive strength at 7 and at 28 days and the results are summarized 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 practical, 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 disaster of national proportions.

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SURVEY OF THE SEISMIC VULNERABILITY OF HOUSING IN TRINIDAD

LOCATION

COUNTY: ______________________ TOWN ______________________

ADDRESS: ____

COMMERCIAL ☐ RESIDENTIAL ☐ OWNER OCCUPIED ☐ APARTMENTS ☐

STOREY 1 ☐ 2 ☐ 3 ☐ EXPECTED OCCUPANCY: ____________

CONSTRUCTION DETAILS

BUILT BY: CONTRACTOR/BUILDER ☐ OWNER ☐

QUALIFICATIONS/EXPERIENCE: ______________________________

____

FOUNDATION:

SOIL TYPE 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐

DEPTH (below O.G.L.) (mm) __________ APPROX. POS'N OF WATER TABLE (mm) __________

RESISTANCE (to digging tools) HARD ☐ MODERATE/MEDIUM ☐ SOFT ☐

SIZE OF FOOTINGS (mm) L __________ B __________ THICKNESS __________

STEEL COLUMN: SIZE (Approx)(mm) ______________________ N/A ☐

R.C. COLUMN: ☐ ○ ▭ SIZE (mm) ________ X ________ HEIGHT________

MAIN REINF: HT (deformed) ☐ MS ☐

Diameter (mm) __________ No of bars/column__________

STIRRUPS: (Shear) HT (deformed) ☐ MS ☐

Diameter (mm) __________ Spacing c/c (mm) __________

FLOOR SLAB: SIZE (metres) L __________ B __________ THICKNESS(mm) __________

NO. OF COLUMNS PER FLR: __________

BRACED? YES ☐ NO ☐

(i) PARTITION WALLS: ORIENTATION:

N-S ☐ E-W ☐ CLAYBLOCK ☐ REINFORCED ☐ PLASTERED ☐

CONC. BLOCK ☐ UNREINFORCED ☐ UNPLASTERED ☐

(ii) STAIRS: N-S ☐ E-W ☐ REINFORCED CONCRETE ☐ STEEL ☐

ROOF TYPE: 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐

CONCRETE

READYMIXED ☐ Supplier: ______________________

Specified ☐ or ○ Strength (MPa): Upper Floor Slab __________ Columns __________

SITE MIXED ☐ Mechanical ☐ Manual ☐

CONCRETE MATERIALS

AGGREGATE : Guanapo ☐ Melajo ☐

Grading: All in ☐ "1/2 and 1/2" ☐ Separated ☐

Nominal Size: Coarse __________ Medium __________ Fine__________

BATCHING (by volume): Fixed Measure ☐ Estimated ☐

Mix Proportions (by volume) ______________________

Cement Dispersion ______________________

Water Addition: Bucket ☐ Hose ☐

WORKABILITY: Stiff ☐ Medium ☐ Collapse ☐

MIX UNIFORMITY: Consistent ☐ Variable ☐ MIX CHARACTER: Harsh ☐ Cohesive ☐

SUPERVISION DURING MIXING: Yes ☐ No ☐

NON DESTRUCTIVE TESTING	MEMBER	READINGS
SCHMIDT HAMMER		
UPV		

REMARKS: ______________________

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NOTES:

A. ROOF TYPE
1. Wood (framing) & "Galvanize"/Aluzinc
2. Wood (framing) & Clay Tiles
3. Wood (framing) & Shingles (asphalt/vinyl)
4. Reinforced Concrete

B. SOIL TYPE
1. Silty Clay
2. Clayey Silt
3. Phyllite (compact)
4. Silty Gravel in some clay
5. Shale
6. Guaracara Limestone
7. Clay

Seismic Reliability Improvement by Retrofitting of Oil Refinery Equipment

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Abstract

Mitigation of potential damage to the built environment can be effectively reached by the seismic reliability evaluation and retrofitting of existing structures and/or installations. This paper presents the experience achieved in a seismic retrofitting programme implemented in parts of a major oil refinery plant, and discusses a simplified probabilistic procedure in order to take decisions among several options based on the reliability of the system and expected material losses. Seismic performance is determined by dynamic analysis procedures in order to evaluate the structural safety of critical areas of the equipment, under the combined effect of seismic actions, gravity and service loads. The procedure is illustrated by a simplified example.

Possible Applications of Isolation Systems in Venezuela to Retrofit Buildings Damaged by Earthquakes and to Improve Building Structural Control

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Abstract

A general and detailed review of different Isolation Systems developed around the world will be included. The U.S., Japan and New Zealand Isolation Systems and their building applications will be evaluated in detail. A selection of the most practical systems to be applied in Venezuela for retrofitting buildings damaged by earthquakes would be considered, also the possibility to apply these isolation systems at new buildings to increase the seismic hazard mitigation and to improve their Structural Seismic response using active and passive control systems.

The analytical techniques to design specific Isolation Systems would be reviewed and some examples of buildings showing their dynamic seismic response will be considered with or without isolation system.

The type of building, considering materials, number of floors, geometry, structural components, dimensions and the subsoil influence on the Seismic Response will be evaluated. Finally the influence of the isolation system costs over the total budget of the building will be analyzed.