A 95

“Over the past years, precast technology has developed tremendously. This BICC conference aims to reveal the potential of architectural precast components, and to promote its use to achieve improvements in productivity, quality and buildability, providing the industry with more options and possibilities to meet the criteria entailed by requirements in today's day and age.

The conference will delve into a wide range of topics, covering structural design, quality assurance, connections and detailing, road construction, and repair to prestressed elements.”

The Building Industry Consultative Council has the pleasure of inviting you for this conference

Venue: **NEW DOLMEN HOTEL QAWRA**

Date: **26th OCTOBER 2000**

Time: **14:00 - 18:00 hours**

CONTENTS

BUILDING INDUSTRY
CONSULTATIVE COUNCIL

Office of the Chairman

Precast Technology
what you need to know

During the course of the past year, he BICC has been pursuing research in the broad areas of construction, enabling the formulation of the Education and Research Thrust. Major themes on research included conservation practices, buildable solutions, health and safety practices and precast concrete technology.

In collaboration with a number of local researchers, a technical publication on design methodology governing structural solutions, was initiated in response to requests by the industry to obtain an aligned methodology in the light of available code of practices.

This assignment involves the drawing up of a structural design example of a typical Maltese three storey terraced house adopting local construction methods including precast components, with a view to develop accurate design methods helping engineers to better understand the behavior and performance of building elements. In parallel, this conference provides an excellent opportunity to attenuate this discussion further, realising that precast technology has developed tremendously locally in tandem with development worldwide.

Precast technology came into use in the 1970s, innovative applications of prestressed concrete and repair methods being developed since then, presenting us with more interesting and challenging solutions.

Precast technology – what you need to know is another conference, which the BICC is holding from time to time as part of its wide education and research strategy for the construction industry at large, this time round efforts focusing on issues and developments pertaining to precast technology.

It is hoped that this conference unveils the potential and practical value of combining the compressive strength of concrete with high tensile strength prestressing steel, inspiring all those present to closely examine the properties, benefits and design methods of prestressed concrete.

BUILDING INDUSTRY
CONSULTATIVE COUNCIL

Office of the Chairman

The conference will systematically discuss a wide range of topics, covering design solutions, recommended detailing and construction, multi storey buildings and the implication of seismic loading.

I take this opportunity to extend my appreciation to the cosponsors of this event, General Precast Concrete Ltd and Ballut Blocks Ltd, who shall also tender a condensed demonstration during the course of this conference.

You may wish to note that this publication is a working document, the actual proceedings being finalised and published in due course.

Robert Musumeci
Chairman BICC

LOCAL PRECAST CONSTRUCTION UNDER EARTHQUAKE LOADING

INTRODUCTION

Our construction has always been considered to act under vertical loading. No tying elements exist between the horizontal floor slab and the vertical walling. Originally it was the "xorok" floor system, later on replaced by the reinforced concrete floor slabs, but they always sat pretty on the supporting masonry walling. So with the advent of precasting in Malta, the material changed, but the workmanship simply shifted from one construction to the more sophisticated system, with no building refinements being achieved.

It may also be ascertained that in precast form, the majority of buildings erected, are less stable than the previous forms of construction. This is due to the precast slabs, in many instances being supported on a separate walling, thus creating a soft structure mainly at ground level. This increased height of unrestrained walling, heightened with hammering of the floor slabs of the various terraced structures at various levels, thus creates a lack of horizontal stability, something which had previously been relied upon for a horizontal tie. A collapse as a child's build up with a pack of cards, is not to be ignored.

The effects on this unsymmetrical construction are to be considered when subjected to earthquake forces. The effects are illuminating, but are an indication of what may be expected under blast loading when pressures ranging from $15KN/m^2$ up to $35KN/m^2$ may be induced, or under any other form of anticipated horizontal forces. Our constructions require stability requirements to be incorporated into the designs, for us to be able to quote the saying, "as safe as houses."

MALTA EARTHQUAKE FACTS

A seismic risk analysis has not yet been drawn up for the Maltese islands, but from the limited data available, the return periods are approximately estimated as per table 1.

Table 1 – Return Periods for Earthquake Intensity

MM-Earthquake Intensity	Return Period (years)	% of gravity
VI	333	2 – 5
VII	1,800	5 –10
VIII	100,000	10 –20

The above subjective educated guess for above Return Periods, classifies an MMVII earthquake as a negligible risk & an MMVIII earthquake as an insignificant risk compared to rock climbing as a high risk, tolerable risks travelling by car and place, low risks travelling by bus and minimal risk due to terrorist bomb.

The worst earthquake related peril to have hit Malta is recorded as at 1693. In John Shower's Book (Ventura, Galea et al, 1994), written 5 days after the Earthquake is mentioned that the roof of the Church of Our Lady Tal-Pilar was thrown down, with part of that of St Lawrence. The church and college of the Jesuits also suffered very much, but the Cathedral and St Paul's Church in Rabat received the greatest damage and are so ruined that they can hardly be repaired. Most of the houses are extremely shattered and deserted by the Inhabitants who now live in Grotto's and under the tents in the fields. He also mentions that the Grand Master was hunting, presumably in the Buskett-Girgenti area, and was in great danger by the falling of a mountain near him. Again de Soldanis in his manuscript Gozo Antico & Moderno, recounts how the sea at Xlendi rolled out to about one mile and swept back a little later "con grande impeto and mormorio" in the earthquake of 1693.

Considering the above damage, rock falls in addition, together with a tsunami, it appears that intensity of the 1693 Earthquake works out at MM VII.

The author had subdivided the Maltese Islands into 4 regions for earthquake hazard (DH Camilleri, 1999), dependent on the geological formation, as per figures 1 & 2, although greatest earthquake damage anticipated in the Inner Harbour region due to older building types with a higher % of substandard dwellings together with highest population density, followed by the Outer Harbour region as outlined in table 2.

Table 2 – **Characteristics of the Sub-Divided Regions of the Maltese Islands**

Region – km^2	**Population Density Person/km ***	**Age Structure of dwellings - % built after 1960**	**% Substandard & inadequate occupied dwellings ****
A - 158.7	2126	56	6.4
Inner Harbour* -16.9	5258	28	11.3
Outer Harbour* - 33.3	3389	66	5.7
B - 33.0	476	56	6.1
C - 54.6	298	76	3.6
Gozo - 68.7	422	60	5.9

Source: Census of Population & Households (Malta) 1995

* the highest population density occurs in Senglea in the Inner Harbour region at 22,744 persons/km.
** Zammit (1997), Miljanic Brinkwork (1997)

EARTHQUAKE BUILDING CLASSIFICATION DATA

Table 3 - Types of Building for damage due to Earthquake Exposure

Type	Description	Base shear design % of gravity
A	Building of fieldstones, rubble masonry, adobe, and clay. Buildings with vulnerable walls because of decay, bad mortar, bad state of repair, thin cavity brick walls, etc.,	0.5
B	Ordinary unreinforced brick buildings, buildings of concrete blocks, simple stone masonry and such buildings incorporating structural members of wood;	0.7
C	Buildings with structural members of low-quality concrete and simple reinforcements with no allowance for earthquake forces, and wooden buildings the strength of which has been noticeably affected by deterioration;	0.9
D_1	Buildings with a frame (structural members) of reinforced concrete	2-3
D_2	Buildings with a frame (structural members) of reinforced concrete	3-4
D_3	Buildings with a frame (structural members) of reinforced concrete	6
D_4	Buildings with a frame (structural members) of reinforced concrete	12
D_5	Buildings with a frame (structural members) of reinforced concrete	20

Source: Swiss Re (1992)

NOTE: the subscript to a D Building denotes the base shear to be resisted, as given in adjacent column.

In Malta a few buildings are classified as type B. These would be restricted to old rural deteriorated dwellings exceeding 150 years in age or old deteriorated buildings in Valletta, which due to little maintenance, stability has been impaired due to ingress of water. Type A are limited to deteriorated old agricultural sheds found in fields. Most masonry buildings and most buildings in concrete frame would be classified as conforming to type C. The more rigid buildings, satisfying stiffness regularity and symmetry in plan/elevation layout, are classified D_1.

From table 1 is noted that for no damage to be suffered during an MMVI, building type to be D2/D3, during MMVII building type D3/D4 and MMVIII building type D5.

<u>ANTICIPATED DAMAGE MATRIX FOR MALTESE PROPERTY TYPES FOUNDED ON ROCK & BEING MODERATELY ASYMMETRICAL & IRREGULAR</u>

The Mean Damage Ratio (MDR) table 4 is the average damage to buildings of about identical vulnerability and architectural characteristics, expressed as a percentage of their new value.

TABLE 4 - Mean Damage Ratio (MDR) For Building Type Against Earthquake Intensity founded on rock.

BUILDING TYPE	**A**	**B**	**C**	**D_1**	**D_2**	**D_3**	**D_4**
EARTHQUAKE INTENSITY	MDR	MDR	MDR	MDR			
V	4%	**2%**					
VI	10%	**4%**	**1%**				
VII	45%	**20%**	**10%**	**3%**	*2%*		
VIII	60%	**45%**	**25%**	**12%**	*6%*	*3%*	*1%*
IX	80%	**60%**	**45%**	**30%**	*17%*	*12%*	*6%*
X	100%	**80%**	**65%**	**55%**	*35%*	*25%*	*17%*
XI	100%	**100%**	**100%**	**85%**	*60%*	*50%*	*35%*

Source: Camilleri DH (1999)

The present majority range of Maltese buildings fall within types B-D_1

For buildings founded on softer material than limestone, the **MDR** is taken as the progressively corresponding higher value on the scale. For example if a type C building founded on clay is subjected to MSK-VI, its **MDR** is to be taken at 10%. Further, if founded on a poorly back-filled disused quarry, an **MDR** of 25% to be taken.

During the past 25 years the building construction in Malta has been subjected to changes, brought about from the economic expectations of landed property. The commercialisation of buildings has opened up the layout especially at ground floor level, obtaining a flexible soft structure, whilst on the upper levels rigid structures in masonry are still being constructed, due to the economic availability of good building stone. Another recent innovation is the availability of precast prestressed slabs, which are ideal for obtaining large open spans necessary for the car parking facilities required by our society. These slabs, normally sit freely on the supporting structure, with no tying provided to the rest of the structural system. In earthquake design the tying of the various structural system is a requisite to obtain a rigid diaphragm tying the whole building together.

REGULARITY & SYMMETRY

It is recognised that an asymmetric or irregular design in buildings will suffer a higher mean damage ratio (MDR) than regular structures exposed to the same shaking.

A building may be slightly irregular or asymmetric due to the following factors:

- A small part is of different elevation
- The floor area is reduced from a certain storey upwards
- Elevator shafts or columns are asymmetrically arranged
- A part is of different stiffness

If a building has an "L"- shaped elevation or an "L"-shaped floor plan or if foundations are resting on different sub-soil, the earthquake exposure is greater.

Elevations are easy to evaluate as regards asymmetry, but it is important to inspect all sides of a building. The inspection of floor plans should take all into consideration, as there could be major differences in plan between the ground and upper floors.

More difficult to assess are irregularities and asymmetries, associated with the internal properties of buildings, e.g. mass, stiffness or dampness.

An elevated water tower is an example of a non-uniform distribution of mass and thus irregularity. A cantilevered canopy could be another example.

The absence of walls at ground floor implies a substantial transition in stiffness and some difference in mass and damping between the ground and upper floors. A further irregularity in stiffness, frequently found in commercial and public buildings is due to the greater height of the ground floor. Unfortunately this feature is often combined with a soft ground floor, as there are few or no walls lending lateral support to the columns. Such designs make a building a potential death trap. Symmetrically arranged stair and lift shafts render such buildings better risks. Hotels often belong to the category of buildings of such asymmetry, but not only have a lobby, but also large dining halls and restaurants etc. on the ground floor.

In low-rise masonry construction, garage type structures, are not uncommon, where the structure consists of a box with one side omitted. The following details would achieve an improvement to earthquake exposure. **Openings in exterior walls should be at least 500mm from the corners. Interior doorways should be at least 2 wall thickness away from the end of the wall. Openings in walls should be at least 500mm apart.**

Normal factory buildings perform quite well, provided there are no pronounced irregularities like extensive window bands or discontinuities in the resistance of columns, for example at the level of travelling cranes.

A factor shall be obtained for a highly irregular building, with abrupt change of stiffness between floors. The MDRs obtained previously were for a weighting factor fr_1 of 1.3 for irregularity and asymmetry in relation to a recessed elevation of building (vide shapes 1.3/1.4 in table 1, Appendix A), a similar value fr_2 of 1.3 (vide shapes 2.3/2.5/2.10/2.12 in table 2, Appendix A). in relation to an L-shaped floor plan whilst a value fr_3 of 1.5 in relation to internal irregular layout of walls of building (vide shapes 3.4 in table 3, Appendix A) giving a global factor of

$$\mathbf{Fr_A = 1.3 \ X \ 1.3 \ X \ 1.5 = 2.5}$$

Soft designs encountered locally could incorporate a soft ground floor, with columns in a section of this level together with a stiff heavy structure on top, this elevation irregularity produces a factor fr_1 of 4 (vide shape 1.8 in table 1, Appendix A). A T-shaped floor plan with increased damage probability at both sides of intersection produces a factor fr_2 of 1.5 (vide shape 2.6 in table 2, Appendix A). For the internal arrangement in different spans of irregular arrangement of internal walls leads to a factor fr_3 of 2.5 (vide shape 3.4 in table 3, Appendix A).

In this case global factor works out at:

$$\mathbf{Fr_B = 4 \times 1.5 \times 2.5 = 15}$$

The effects of asymmetry lead to an amplification of MDR given by

$$\frac{\mathbf{Fr_B}}{\mathbf{Fr_A}} = \frac{\mathbf{15}}{\mathbf{2.5}} = \mathbf{6\ times}$$

The local buildings which fall into this category are Buildings Type C, and D1 and an amended damage matrix is proposed to cater for higher asymmetry and irregularity. It is being assumed that future earthquake designs for Building Types D_2-D_4 would only have normal irregularity.

TABLE 5 - Amended Damage Ratio Matrix for Higher Irregularity & Asymmetry

BUILDING TYPE	C	D_1
EARTHQUAKE INTENSITY		
V	10%	5%
VI	30%	18%
VII	60%	40%
VIII	100%	72%
IX	100%	95%

Source: Camilleri DH (1999)

From the above, it appears that an elevated Terraced house supported on precast planks at ground level would experience a 10% damage loss at an of MSK V, whilst high level apartments, having a soft floor would be a total loss at an of MSK VIII. Unreinforced masonry construction as not being earthquake resistant is recommended, not to exceed 2 stories at the most.

In terraced blocks, the effects of hammering must be considered, where a soft building would cause damage to an adjacent rigid designed building.

The **Damage Probability Matrix (DPM)** Table 6 for buildings now follows. The **DPM** shows the effects of **MDRs**, differing substantially from that assumed, it could well be that the loss is much higher than given by the **MDR.**

TABLE 6 - Damage probability matrix for buildings (DPM)

Damage class % of value			**Mean Damage Ratio (%) (MDR)**									
			1.5	3	5	10	25	37.5	50	60	70	85
0	- 1.5	(A)	83	73	60	36	9	2				
1.5	- 3	(B)	17	25	26	23	9	3				
3	- 6	(C)		2	10	18	11	5	2			
6	- 12.5	(D)			3	12	18	12	6	2	1	
12.5	- 25	(E)			1	8	24	24	15	7	3	
25	- 50	(F)				3	19	28	29	23	18	10
50	- 100	(G)				1	10	29	48	68	78	90

Source: Swiss Re (1992)

The highest damage class (G) in Table 6 covering damage between 50% to 100% is of particular importance as most causalities and severe indirect losses due to business interruption are associated with these severely damaged buildings.

Table 7 is more useful than Table 6 in showing the approximate % of the homogeneous buildings in the 80-100% damage class depending on the MDR of the sample.

TABLE 7- Percentage of Buildings with 80-100% damage depending on MDR

MDR	10	20	30	40	50	60	70	80	90
Percentage	0.25	3.5	10	20	30	45	56	70	85

Source: Swiss Re (1992)

As an example, let us assume a moderately asymmetrical and irregular type C building founded on rock subjected to an earthquake of intensity MSK VII. From table 2 MDR is taken at 10%.

From Table 6 for an MDR of 10% -
36% of sample subjected to Damage Class A (0-1.5%),
23% subjected to Damage Class B (1.5-3%),
18% subjected to Damage Class C (3% - 6%),
12% subjected to Damage Class D (6% - 12.5%)
8% subjected to Damage Class E, (12.5% - 25%)
3% subjected to Damage Class F (25-50%)
1% subjected to Damage Type G (50%-100%) which includes casualties and loss of business.

From Table 7 for a MDR of 10%, the percentage of buildings subjected to a damage varying between 80-100% given at 0.25%.

This exercise could be carried further to see how much of this damage is non-structural.
For a type C building 70% of the above mentioned MDR is for non-structural components,
for a type D building this value increases to 80%,
for D_2 becomes 90%,
for D_3 becomes 98%
and D_4 becomes 99.9%.

In Malta the proportion of the shell cost to finishes varies in the ratio of 1:2, whilst for a more sophisticated commercial building type, this increases to 1:5. The amount of non-structural damage effects the number of people injured, and has a great effect on business interruption, as it is not so much the damage to the structure but predominantly the damage to non-structural components. As regards ease of repair, the chief problem is not so much the labour and cost, as the obstruction and the time involved in repairs and replacements, creating a mess in the working area, interfering greatly with normal occupation and causing other nuisances.

Buildings which incorporate a high or very high collapse probability, such as those constructed in poor masonry, those having a soft reinforced concrete frame with little strength, or badly assembled prefabricated buildings will kill many people as they fail and leave few to be injured. As a rule of thumb, it may be assumed that about a 1/4 - 1/8 of the population in the 80-100% (Table 7) damage class buildings will be killed.

As the quality of buildings goes up, the importance of structural failure dwindles, while the contribution of non-structural damage grows. Buildings with failure prone non-structural parts will have a higher number of injuries in and around such buildings.

RECOMMENDATIONS & CONCLUSIONS

From an enclosed stability structural calculation in Appendix 'B' of a 2-storey terraced house overlying an 11 crs high garage supported on 6.0m spanning prestressed slabs, it is concluded that stability is lost when subjected to an earthquake of intensity MSK VI/VII.

From Table 2, note that the mean damage ratio (MDR) for present type B buildings varies from 2% for MM5 up to 45% for MM8. If our wall construction is modified to include an outer skin of masonry, with the inner skin constructed in hollow concrete blockwork, infilled with concrete and reinforced at corners to tie in with the overlying concrete floor slabs, this tied building would then be classified as a type C. The MDR would then decrease to 25% at MM8. To be noted that for a type 'B' building, non-structural damage would amount to 50% of MDR, whilst increasing to 70% for a type 'C' building. As the quality of building goes up, with the contribution of non-structural damage increasing, the death rate reduces, but a higher number of injuries occur (Swiss Re, 1992).

From stability calculations as per Appendix C, referring BS 8100, it is noted that for a 6.0m clear span, a 1 in No 20mm ∅ bar is to be placed at 3.6m centres in grouted void of planks. This is to be tied to peripheral 1 in No 10mm ∅ bar placed in concrete padstone. This peripheral tie is to be linked to a vertical tie consisting of 1 in No 25mm ∅ bar placed vertically in concrete filled block work at 3.6m centres.

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Camilleri DH (1999), "Vulnerability of buildings in Malta to earthquake, volcano & tsunami hazard" *The Structural Engineer* Nov99 vol77No22 SETO, UK.

Central Office of Statistics, (1995), Census of Population & Housing - Malta, Vol6 Dwellings, Malta.

Swiss Re Zurich, (1992), "Earthquake and Volcanic Eruptions: a Handbook on Risk Assessment", Switzerland.

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Ventura F., Galea P., et al (1994), "Mdina and the Earthquake of 1693", Heritage Books, Malta.

Zammit J., (1997), Miljanic Brinkwork M., (1997), Housing situation 1997- 2007 (unpublished).

APPENDIX A

Tables 1–3. The first Table (Nos. 1.1–1.13) contains various examples of elevations, ranging from symmetrical to very asymmetrical. The corresponding parameters (fr_1) indicate the approximate malus which should be considered when evaluating the damage rate of such buildings. Such parameters are not to be considered constant but their effect varies because of damage saturation.

In the range of low damage ratios the effect of asymmetry will in general be much more pronounced than in the case of higher damage ratios, where damage saturation becomes progressively more important.

The second Table (Nos. 2.1–2.13) shows examples of floor plans and the corresponding correction factors fr_2. The above comment applies here as well.

The third Table (Nos. 3.1–3.10) relates to internal properties of buildings like features of design, distribution of masses and of damping and foundation properties. Here again the above remarks must be considered.

Table 1: Generalized quantification of the influence of irregularity and asymmetry on damage in relation to elevations of buildings

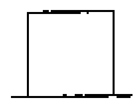
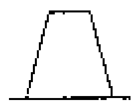
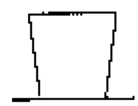
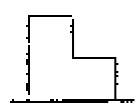
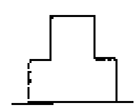
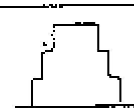
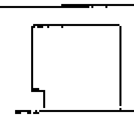
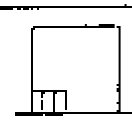
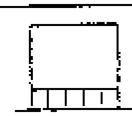
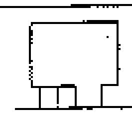
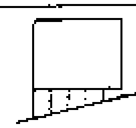
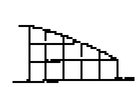
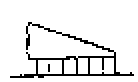
No.	Elevation	Remarks	fr_1
1.1		Both views are absolutely regular and symmetrical. If this holds for the entire building's structure and important non-structural parts, and foundations the risk is best.	1.0
1.2		Building in the shape of a pyramid for one or both elevations. If symmetry is observed in all other aspects, risk is similar to 1.1, ore even slightly better.	1.0 0.6
1.3		Inverted pyramid, sometimes with vertical walls for the ground floor. This structure is top-heavy and therefore not the best risk.	1.3
1.4		L-shaped elevation which results in an elevation of exposure in the transition zone, particularly where the lower section is attached.	1.3
1.5		Building of the shape of an inverted T. Enhanced exposure at the regions where the lower parts meet the tower	1.5
1.6		Building with several setbacks leading to transitions of masses, stiffness, and damping at various floors and higher exposure there.	1.8
1.7		Upper floor protruding. Frequent in rainy tropical regions for commercial buildings to cover part of the footwalk. Depending on relative importance of upper section risk may be increased quite substantially.	1.5–3
1.8		Soft first floor on one side, more stiff on other one where walls fill space between columns. Depending on amount of irregularity this design can be dangerous.	1.5–3
1.9		Mostly free-standing columns on ground floor resulting in soft storey there and stiff, top-heavy structure on top. Dangerous design. Very dangerous in case of resonance.	3–10
1.10		Free standing columns on one side, protruding upper storeys on other one. Considerable asymmetry results in substantial exposure. Dangerous to very dangerous design.	3–10
1.11		Building on sloping ground. Considerable asymmetry results high risk of collapse.	5–10
1.12		Design found in halls, theatres, and the like. Substantial asymmetry can make serious failures of members quite probable.	3–10
1.13		Sport stadiums are sometimes of this shape. If an earthquake occurs when they are packed to capacity, the risk is substantial.	5–10

Table 2: Generalized quantification of the influence of irregularity and asymmetry in relation to floor plans of buildings

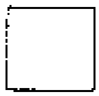
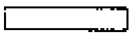
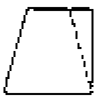
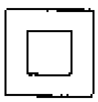
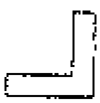
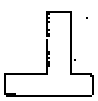
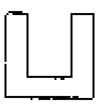
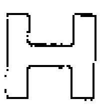
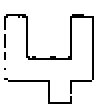
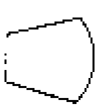
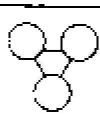
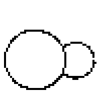
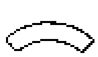
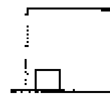
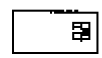
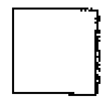
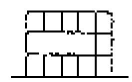
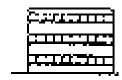
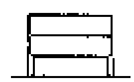
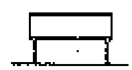
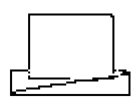
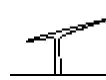
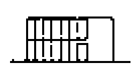
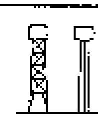
No.	Floor Plan	Remarks	fr?
2.1		Symmetrical lay out. If no other aggravating factors are found the risk belongs to the best category.	1.0
2.2		Although this building is by itself regular, the non-uniform arrival of ea..quake energy can lead to problems in long buildings.	1.2
2.3		Buildings with angles different from rectangular ones are sometimes found at street corners. Such plans invite torsional shaking.	1.3
2.4		Buildings with a yard in the center or a patio may increase damage probability if differential shaking between the limbs may cause dangerous distortions in the corner sections.	1.3–2
2.5		L-type floor plan with an enhanced risk of damage in the corner region.	1.3
2.6		T-type plan with increased damage probability at both sides of the intersection.	1.5
2.7		U-type plan which leads to an enhanced exposure in both corners.	1.8
2.8		H-type plan with higher damage probability in the corner regions.	2
2.9		Complex floor plan. The more wings are interconnected to a »back-bone« building the more likely becomes damage in general and at places of intersection.	2.2
2.10		Floor plan for halls, auditoriums, theatres, etc. which increases the risk of torsional shaking.	1.3
2.11		Cylindrical buildings have become fashionable with some architects. If one of the towers is not stiffer or softer (special elevators or their arrangement), symmetry is good.	1.1
2.12		Example of an asymmetric connection of circular floor plans leading to torsional problems.	1.3
2.13		Curved buildings are asymmetric and in addition often long, both features increase exposure.	1.2

Table 3: Generalized quantification of the influence of irregularity and asymmetry on damage in relation of internal features of buildings

No.	Internal properties	Remarks	
3.1		Asymmetric opening in shear wall. This is a simple case of irregularities which may be introduced into shear walls by size and arrangement of openings.	1..
3.2		Asymmetric arrangement of staircase and elevator well with enhanced stiffness of one side. If this structure would be attached to the outside of the building asymmetry would be even more pronounced.	.2
3.3		Shear wall or retaining wall on one side makes building much stiffer there introducing torsional loads.	1.2-
3.4		Different spans or irregular arrangement of substantial internal walls renders building irregular. If the hall assumed here in second floor would be large this could produce a soft storey.	1.5-
3.5		If continuous window-bands interrupt fill-in walls and produce short column effect damage probability is substantial	2-
3.6		Substantial transitions in stiffness leads to increased damage probability	1.2-
3.7		If columns are offset producing a cantilever action on beams vertical accelerations and overturning moments enhance the probability of serious damage.	1.5
3.8		In the case shown here the right side of the basement sits on hard ground whereas the left one is supported by soft material (piles there to hard strata could represent 1.1)	1.3-
3.9		In this hypothetical canopy the mass of the roof section is quite to the right of the columns. This will lead to serious twisting in the structure.	2-
3.10		The left section of this industrial or commercial facility is glazed whereas the right one has fill-in walls or pre-fabricated panels. The consequence is asymmetry in mass and in damping properties.	1.2-
3.10		Top heavy buildings and parts of it, here symbolized by water towers have a high probability of failing unless designed very well. Due to a low fundamental frequency they are exposed to distant quakes if on softer soil varieties.	2-1

APPENDIX A

Structural check of adequacy for masonry walling supporting overlying 2 residential floors on a clear span of 6.0m such as in construction with prestressed concrete slabs.

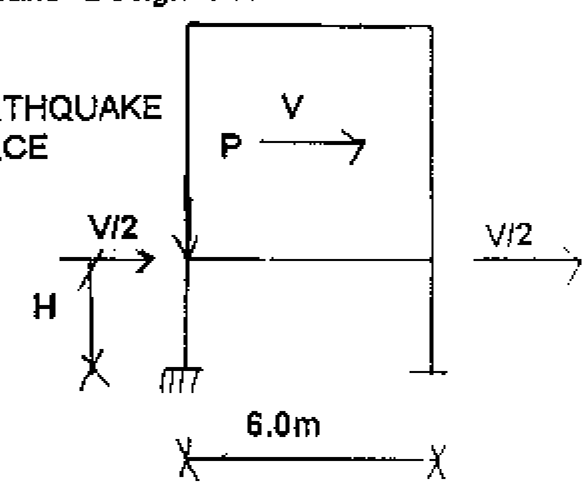
According to American UBC code

V = ZIK (CS)W

- (CS) does not need to exceed 0.14
- K for this type of structural layout taken at 2
- I being an occupancy factor, for domestic purposes taken at 1
- W is the total dead load taken at 166KN/m
- Z depends on intensity grade - for VI taken at 3/16 for VII taken at 3/8
- V = 8.75KN/m for intensity VI
- V = 17.50KN/m for intensity VII

Loading from above on this b = 225mm thick masonry walling P = 225KN/m including dead and live loads, with a storey height H of 3.00m.

From a method suggested by D. Key in *'Earthquake Design Practice for Buildings'*



V/2 = Pb/2H
V/2 = 225 X 0.225/3.2
V/2 = 8.43KN/m
V = 16.86KN/m (from above satisfies intensity VII)

X_c = b/2
= 0.225m/2
= 0.1125m

equivalent stiffness given by:
$K_e = V/X_c$
= 8.43/0.1125
= 74.93KN/m (74,930N/m)
whence the natural equivalent natural frequency fe is given by:

$$fe = \frac{1}{2\pi}\left\{\frac{K_e}{P \times 1000}\right\}^{1/2}$$

$$= \frac{1}{2\pi}\left\{\frac{74{,}930}{225 \times 1{,}000}\right\}^{1/2}$$

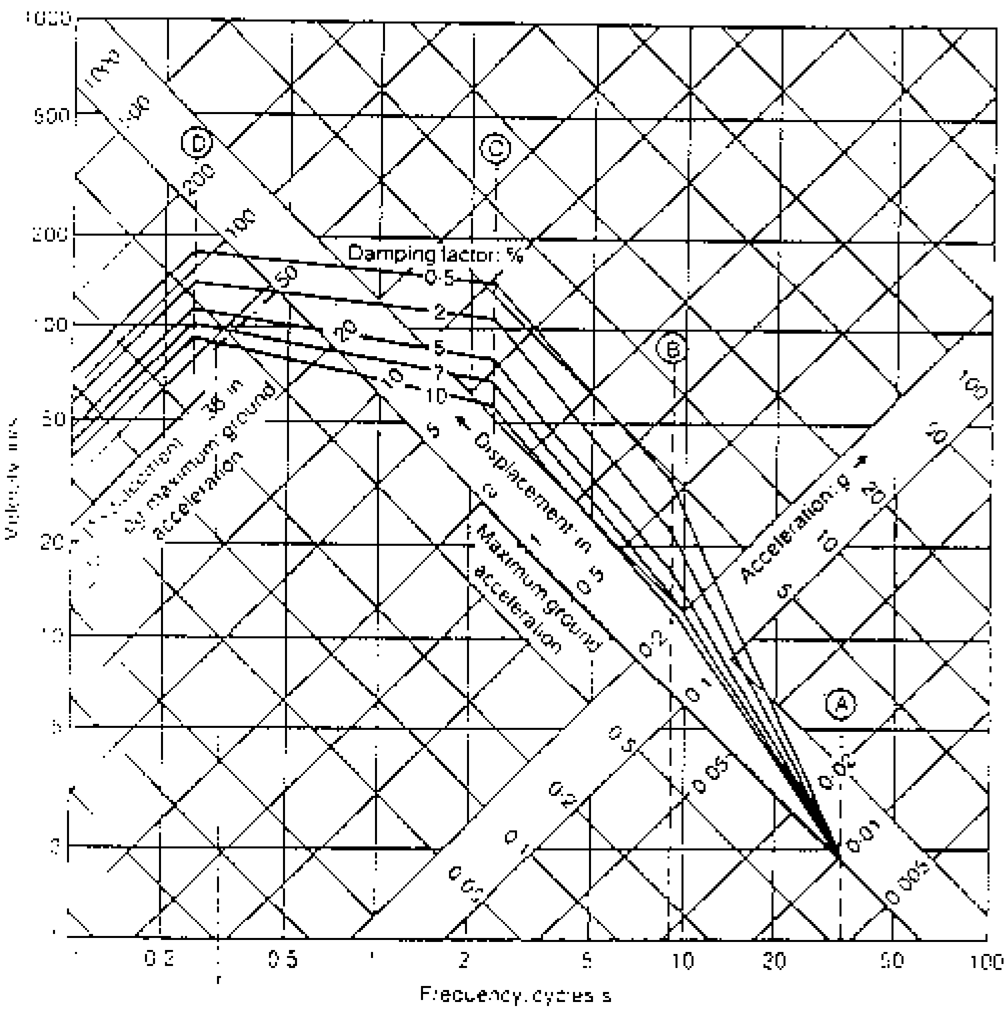
= 0.29Hz

From earthquake design spectrum of ASCE given below for a frequency of 0.29HZ and a masonry damping coefficient of 10%, x = 1.25m for a peak ground acceleration of 1.0g.

Hence the wall as subjected to Xc = 0.1125m will be stable for accelerations up to:

= 0.1125/1.25
= 0.09g i.e. stable up to MSKVI ~~(see page 26)~~

note that if seating of prestressed planks on supporting masonry wall is inadequate producing eccentricities, not an uncommon feature on construction sites, then stability would be reduced even further.



APPENDIX C

From B8110: Part 1 : 1985 Structural Use of Concrete dealing with internal tie Cl. 3.12.3.4

Cl. 3.12.3.4.2 gives the internal tie to be capable of resisting a tensile force KN/m width, being equal to the greater of

$$\frac{(g_k + q_k)}{7.5} * \frac{L_r}{5} * F_t$$

or 1.0 F_t

where F_t is the lesser of $(20 + 4n_o)$ or 60, where n_o is the number of stories

For a 20storeyed terraced house with u/lying 6.0m open span basement

$F_t = 30 + 4.3 = 32KN$

Thus $\frac{(g_k + q_k)}{7.5} * \frac{L_r}{5} * F_t$

$$= \frac{(5.4 + 1.5)}{7.5} \frac{6}{5} X\ 32 = 35\ KN$$

A_s (req) = 35KN/460N/mm^2 = 76mm^2/m (i.e. 1-20mm ∅ bar every 3.6m centres).

Cl. 3.12.3.5 deals with peripherals ties, which should be capable of resisting a tensile force given by F_t, located within 1.2m of perimeter wall.

From above this peripheral tie is to consist of 1-10mm ∅ bar placed in concrete continuous spreader.

This peripheral ties is to be linked with a vertical tie F_v given as a tensile force, equal to the max design ultimate dead of imposed load, received by wall from any one storey (Cl. 3.12.3.7)

F_v = 55KN/m

If this vertical ties is to coincide with internal horizontal tie at 3.6m centres, then

A_s (req) = 55Kn/m X 3.6m/460N/mm^2 = 430mm^2

The vertical ties is satisfied if 1-25 mm ∅ bar is provided at 3.6m centres.

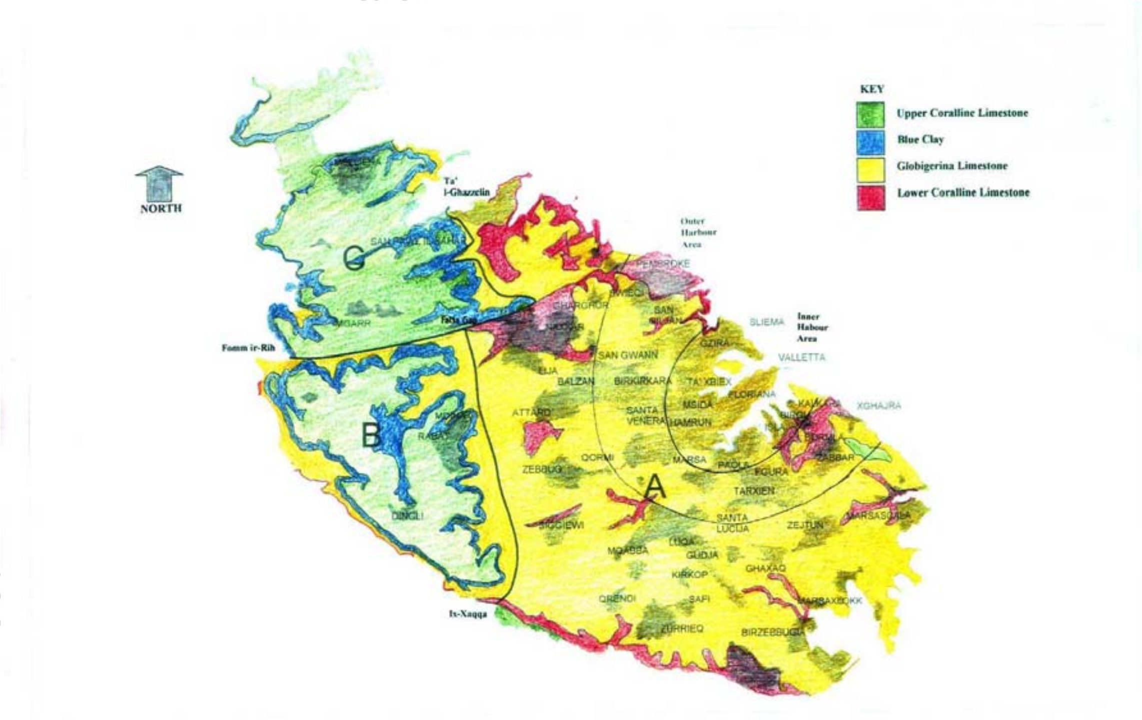


Fig. 1 Malta : A simplified geological map.

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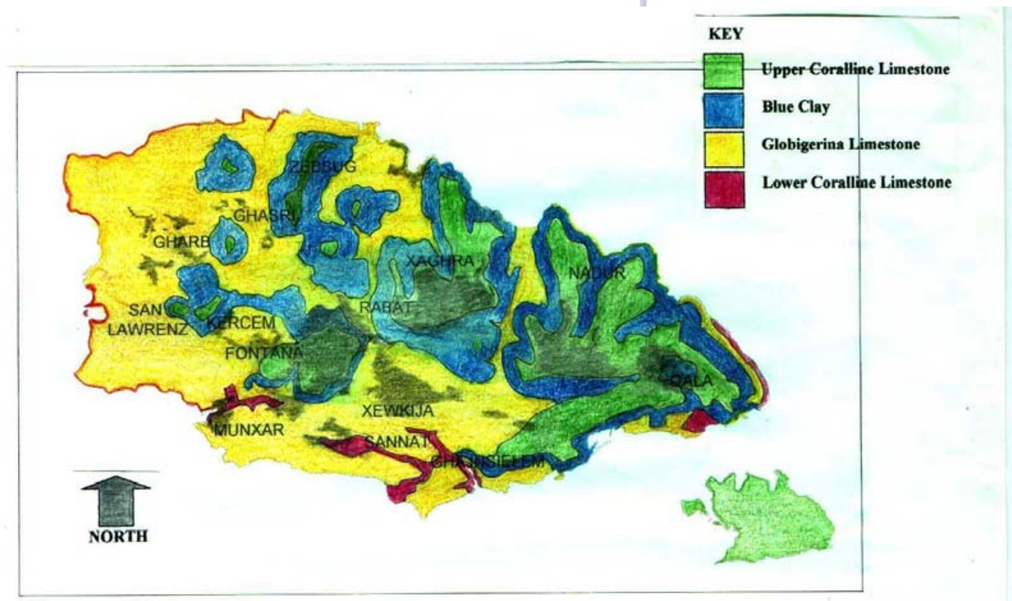

Fig. 2 Gozo: A simplified geological map.

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