Natural Disasters

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The Maltese Islands, situated between Sicily and Tunisia, occupy an area of 315km², with a shoreline 137km long and a current population of 378,132. The islands lie in the middle of an extensive fault system tending approximately NW – SE affecting the Central Mediterranean from Tunisia to Sicily. The Sicily Channel forms part of the relatively stable northernmost platform of the African continent, separating the island of Sicily from the North African Coast.

The geology of Malta consists of a limestone sedimentary formation (Table 1) that was originally deposited at the bottom of a warm shallow sea during the Oliga Miocene period of the Tertiary Era.

The building material most widely used in Malta is the globigerina block known as 'franka'. A mortar is used consisting of 1 part cement, 2 parts sand and 10 parts stone dust which corresponds to a Grade IV mortar (BS5628), whilst characteristic crushing strengths for (GL) and (LCL), (see table 1) are 20N/mm² and 75N/mm² respectively. Due to the difficulty of dressing (LCL) its use presently is very limited due to economies of use. Old buildings close to the sea may have the lower storey in LCL, owing to its greater resistance to deterioration.

Due to the absence of available timber, floor slabs were in 1.0m length masonry slabs, supported on masonry arches at ground level, with timber beams used at upper levels. During the middle of the 19th century, the timber beams could have been replaced by steel joists. Since the last war this form of construction has gradually been replaced by reinforced concrete slabs.

The majority of Maltese buildings consist of a load bearing masonry system with floor slabs supported on 225mm or 150mm thick limestone walling. At the lower level framing concrete beams or precast prestressed slabs may be introduced to present an open layout for car-parking or commercial use.

The faults, along which earthquakes occur, are continuous through Malta and Gozo. Some of the faults are extinct, but others are young and still active.

In John Shower's book(1), written 5 days after the 1693 Earthquake it 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 grottos and under tents in the fields".*

Further *"the Grand Master was hunting and was in great danger by the falling of a mountain near him".* During the same 1693 Earthquake, Agius De Soldanis in his manuscript *(Gozo Antico and Moderno)* recounts how at "*Gebel Sannat, a slice of rock was detached to the sea below whilst the sea at Xlendi rolled out to about one mile and swept back a little later.*" Considering the above damage, rock falls and tsunami, it appears that the intensity of the 1693 Earthquake registered MSK VII.

In "Seismic Hazard in the Maltese Islands"(2) it is concluded that observations of recent earthquake activity around the Islands indicates, at first sight, a low level of activity with small magnitude events (<3.5) occurring at low rates. The occurrence of a magnitude 4.5 event close to Malta in 1972 together with the reported 1693 earthquake shows that it would be irresponsible to dismiss the hazard as negligible.

This article is based on findings of a report commissioned by the Malta Insurance Association.

Current Earthquake Design

The design of normal modern buildings generally follows rules laid down in codes, which lay down minimum requirements, being gross simplifications and generalisations incorporating uncertainties of sometimes considerable magnitude. The basic philosophy of design is the protection of human life and the avoidance of major structural damage, not the reduction of damage. "Structures in general should be able to resist minor earthquakes without damage, but with some non-structural damage, resist major earthquakes of severity without collapse but with some structural as well as non-structural damage".(3)

Currently no building regulations are in force in Malta, but a draft (4) is being proposed to become operational. In this draft design, a predictable level of seismic action is to be catered for dealing with special categories of construction works. These are to comprise hospitals and ambulance depots, main utility buildings, e.g. power stations, fire engine depots, fuel and gas storage installations, bridges and underpasses on major arterial routes, buildings designed to accommodate people who have some impairment in mobility, free standing buildings of 20.0m heights, and buildings used by large assemblies of people.

Building Types Found In Malta

Rubble masonry building, as found in old buildings in Valletta or in the villages being over 200 years old is brittle. The buildings are made of stone set in earth and such structures tend to fall apart even if shaking is moderate at MSK V.

Damage to plain masonry is often concentrated around openings following the mortar joints. Cavity double walling poses a further problem, as the bondstone may not be sufficient for the resultant pop-out of one skin due to little strength in the plane of earthquake distortions. Reinforced block masonry, especially at corners tying in with the reinforcement of the concrete floor slab together with good workmanship in grouting up the reinforcements, would be a drastic improvement over Malta's present state of the art in the construction of masonry buildings.

The concrete buildings constructed to date generally fall short of recommendations given by Earthquake codes for detailing methods of reinforcement, mostly in the tying of column-beam joint layouts and in the positioning of stirrups in beams and columns. Special care is also needed with prefabricated buildings, as their very design is often deficient as regards adequate interconnection. If the workmanship also leaves much to be desired, the compounded effort could lead to particularly severe damage.

Evaluation of Damage & Loss to Earthquake Exposure

The most important factors to be borne in mind are:
Subsoil in which the risk has been built or erected

Material used in building

Workmanship

Sensitivity – relates to machinery, plant and equipment which go into a factory, chemical plant or power station.

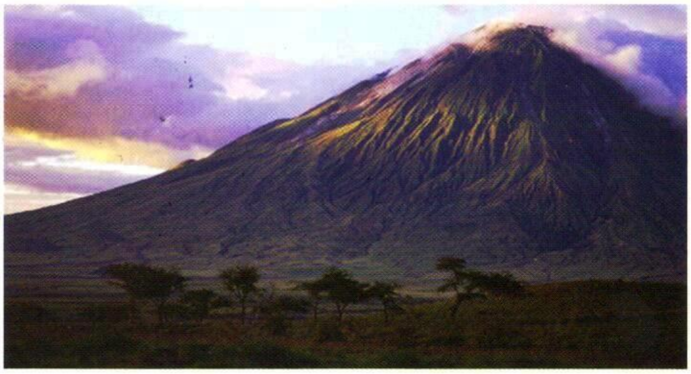
Regularity & Symmetry

Non-structural Damage

Fire Exposure – due to the increased probability of ignition, of the escape and spread of inflammable material, and of the failure of fire-fighting facilities.

Table 1 – The Geology of Malta

Malta's geological succession	Max Thickness	Use
Upper coralline limestone (UCL)	175m	Lime production or known as 'Gozo marble'
Greensand	16m	Deteriorates but may be found in rubble walls
Blue clay	75m	
Globigerina Limestone(GL)	227m	Easily working, used as a building block
Lower coralline limestone (LCL)	120m (visible)	Crushed for concrete aggregate or road base



Vulcanism

There are 13 active volcanoes in the Central Mediterranean area with a chain density of 68 km. The general rate of activity is related to the chain density, being the average distance between alternate volcanoes in a particular region. Eruptions in Central America with an average chain density of 37 km and Japan (42 km) are somewhat higher than in Central Mediterranean (68 km) but higher than in the northern island of New Zealand (88 km).

The Volcanic Explosivity Index (VEI), based on the volume of products, eruptive cloud height, descriptive terms, and other measures is to produce a simple 0 to 8 index of increasing explosively, defined in Table 2.

For the Central Mediterranean the return periods in years for various VEI's approximate to, as given in Table 3.

Mount Etna, situated 220 km due north of Malta, is the largest active volcano in Europe that erupts fairly regularly. It does not seem to have exceeded VEI 3 over the last 3,500 years, but its 2 caledras and its rather viscous lava are a warning that this is not an absolute rule. Its extensive magna chamber amounts approximately to 550 km^2 with a volume estimated at 1,600 km^3 on an ellipsoid structure extending horizontally 22 by 31km and vertically 4 km. Etnean eruptions tend to be less explosive and therefore produce less fine-grained fragmental debris and ash. Etna erupted a total of 37 times during the 18th and 19th Centuries and has erupted 6 times so far during the 20th Century. In 1669 (VEI 2-3) the volume of lava discharged from Etna is estimated at 1 km^3, whilst in 1971-1981 it was estimated at 0.1 km^3. The greatest distance of lava flows measures 240km in Kenya.

Other volcanic areas include Pantelleria and Limosa roughly in line with Malta. Further north are Ustica, the Aeolian Islands 340 km away together with Vesuvius 570 km away, further up.

In 1906, the height of column reached by steam ejected from Vesuvius reached 13 km. A height of 50 km with fine ash was recorded in Krakatoa(1883). During 79 AD the volume of solid material ejected from Vesuvius during an explosive eruption was estimated at 4 km^3 (max recorded 1,000km^3). Vesuvius has a span of 5.27 years between each eruption, with a standard deviation of 4.8 years. Last eruption dates back to 1944, which could be a sign that a relatively violent event is probable now. The span of time is longer than the 38 years of repose separating eruptions of 1906 and 1944 both VEI 3.

In 1930, the distance reached by a 30t projectile from Stromboli was 3 km. The greatest distance measured in 1883 was 80 km for pumice stones from Krakatoa. Stromboli tsunami in 1930 by a VEI 3 eruption produced a 2.2m tsunami generated by the shaking of the flanks of Stromboli, which extend far out under the sea. It has erupted on average every 3.25 years, but somewhat irregularly, as shown by the standard deviation of 5.35 years.

Damage From Volcanoes

The damage caused by a volcanic eruption depends primarily on the type and magnitude of the eruption, on the distance between the risk and the source, and on the Wind Direction and Meteorological conditions.

From old observations and on extrapolations, damage from lava flows is generally restricted to nearby terrain, glowing avalanches or pyroclastic flows can bring total destruction to places 10 to 20 km from source, heavy tephra and ash-fall is problematic today both for agriculture and horticulture and as a potential cause of damage to sensitive technical equipment. Corrosive and noxious gases can cause colossal damage in modern technological society.

From the above and the preceding section, the damage that may affect the Maltese Islands appears to be limited to those which, in turn could be the cause of a reduction in visibility, temperature, ash fall, build-up of corrosive and noxious gases, together with effects of pressure disturbance in the air and electrical phenomena.

Ashfall

By considering the areas of ashfall of Tambora (VEI 7) and placed in such a way as to show the hypothetical distribution if one of the South Italian volcanoes suffered a similar fate, together with assumed meteorological conditions, the Maltese Islands could be covered with a distribution of ash and tephra of a thickness more than 25 cm. The eruption of Katmai in 1912 (VEI 6) produced a 10cm layer of ash, 200 km from the vents.

According to R.J. Blong, at 25cm thickness of tephra falls on plants, a rice paddy is destroyed, whilst at 10 cm, some branches break under tephra load and palm fronds also break.

Human beings are mostly endangered due to the exposure of the respiratory tract and of the eyes.

Quarry works tolerate a lot of ash and low maintenance would be required before resuming operation. Electronic and electrical equipment can sustain damage because of the damaging fine particles, their abrasive effects and electrical conductivity.

The danger to flying aircraft should be also mentioned, with the near crash of a jumbo jet cited.

With ash dispersal, the reduction of visibility may amount to total darkness. An eruption in Chile 1932 from Quizapu volcano (VEI 5), 10 mm of ash fell at Buenos Aires, about 1,200 km to the east of the volcano and 50 mm of ash fell at a distance of 950 km. 10 to 20 mm of ash reduces visibility to such an extent that a World Cup soccer match is out of the question, together with the exposure of the players to pneumoconiosis or even silicosis. During the eruption of Mt. Pinatubo in 1991, a typhoon carried ash in a southward direction towards Manila 100 km away. An ash fall of 10 mm caused the International Airport to close for 5 days.

Table 2 – Index of increasing volcanic explosivity

Volcanic explosivility index	Classification	Description	Eruptions (records)
VEI 0	Hawaiian	Gentle and diffusive	443
VEI 1	Strombolian	Gentle	361
VEI 2	Vulcanian	Explosive	3,108
VEI 3	Pinian	Severe	720
VEI 4		Terrific	131
VEI 5	Ultra-Pinian	Cataclysmic	35
VEI 6		Colossal	16
VEI 7		Super-colossal	1
VEI 8		Mega-colossal	0

Table 3 – Volcanic explosivity index (VEI) v. return periods R (in years)

VEI	2	3	4	5	6	7	8
R (Yrs)	80	750	5000	45 000	650 000	16M	8.10^{10}

Pressure Disturbance In The Air

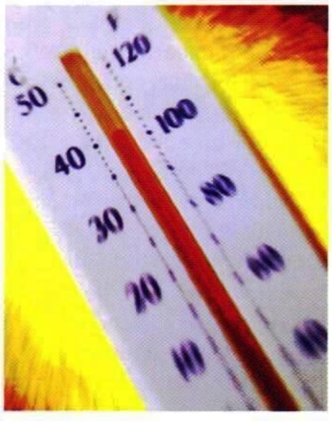
The distance of perception of volcanic explosion at Krakatoa (VEI 6 1883) approximates to 4,653km. At the Batavia Gas Works 160 km from Krakatoa some window-panes and lamps were broken and allegedly some walls cracked. More serious was the throwing down of lamps, the extinguishing of gas-jets and the escape of gas from a gasometer. The effects were similar at Buitenzorg also 160 km from Krakatoa.

Asama produced strong shock waves (VEI 2 – 1911). In Tokyo, at a distance of 300 km, windows were rattled and allegedly even stone weights fell from roofs.

During the eruption of Vulcano in Lipari (VEI 2-3 – 1890) window panes were broken in a 10 km vicinity.

Temperature Effects

Temperature exposure depends on many parameters, like the type of eruption, its time-history, the topography between the vent and area affected, the channelling of the products of eruption, meteorological conditions and these are outlined in Table 4, with the 200km distance approximating to Etna's distance from Malta and likewise the 550km to Vesuvius.



Gases & Acids

Chemicals which can be said to be harmful and abundant in volcanic ejection include compounds of sulphur, chlorine and fluorine, all of which are corrosive.

The Mediterranean lavas are of the andesites type contaminated by the limestone of the earth's crust. Andesites representing the majority of lavas contain about 59% SiO_2, 16% Al_2O_3, 7% iron oxides, 6% CaO, 4% Na_2O, 3% MgO and 2% K_2O.

The Katmai (andesitic cone) eruption (VEI 6 – 1912) caused sore throats at Kodiak, 160 km from the volcano, and eating became almost impossible, whilst every object made of bronze, brass or copper was tarnished black, even if in a drawer inside a sealed house. Washing on the line was reduced to shreds. The rain had so much acid that it caused blisters on the lips and at Latouche, nearly 500 km to the NE, the rain contained so much sulphuric acid that it caused burns on exposed skin.

Electrical Phenomena

During explosive volcanic eruptions even of a small magnitude an extremely high incidence of lightning exists – the only pre-requisite is the presence of dry particles of ash in the air.

The exposure of factories, plants and installations containing material that is explosive, easily inflammable or noxious must be viewed with concern.

When Katmar erupted (VEI 6 – 1912), the Woody Island naval station 150 km away was struck by lightning and burned down.

The growing share of electronic equipment in commerce and industry poses problems, as the damage lightning can cause is not only to the hardware, but also to the software, leading to loss of data.

Inherent Risks Of A Volcanic Eruption

As an example, consider Mount Etna – 200 km away subjected to a VEI 4/5 explosion. From enclosed data, one would expect an ash-fall of 10mm thickness, temperatures would elevate from 50º – 200º C. Ash dispersal would cause a reduction in visibility for about 3 days. The international Airport would have to close for 5 days, with various damage caused to equipment and deterioration of building materials due to heat build-up. A rating assessment may then be calculated estimating the probability of this occurrence.

TSUNAMIS

Tsunami, of Japanese origin, is the internationally accepted term for radially spreading, long period gravity waves caused by large scale disturbance of an impulsive nature. Such disturbances may be caused not only by earthquakes, but also by landslides, by the collapse of a caldera of a volcano in the sea, by the fall of large meteorites and by the impact of asteroids. Earthquake generated tsunamis have caused very grave losses during the second half of this century, although the incidence of the great earthquakes that generate the severe tsunamis was rather nominal. There is a general correlation between earthquake magnitude and size of tsunami – it may be said that only events above intensity M7 cause damaging tsunamis. The accumulation of very substantial developments along shore lines during recent decades has greatly aggravated the exposure to tsunami damage. It had been estimated that some 100,000 people have lost their lives due to tsunamis over the last 100 years.

Present risk assessment is hampered not only because of difficulties in translating losses of the past into today's conditions, but by the relative shortage of large earthquakes, in particular during the period when industrialisation and coastal development was progressing rapidly along most shores.

The waves generated by tsunami are not comparable to ordinary water waves, as considerable draw down and run-up occurs. Due to this, the action of tsunami waves is far more forceful and damaging than the action of storm-generated waves. There is generally a succession of waves, possibly over a 2 hour period, with the first wave not being the worst one.

In the Nihonkai Chubu, Japan earthquake (M-7.7 1983) 3m high tsunami waves carried inland very heavy tetrapods installed for the purpose of protecting the coast against waves. These tetrapods would have resisted much larger ordinary waves.

The run-up height depends on many factors, being higher for places in a V (Xlendi) or U-shaped (M'Xlokk) bay. Reefs or a large expanse of shallow water tend to protect the coast, offshore submarine ridges, however may increase the wave height.

20% of the recorded Mediterranean tsunamis have been damaging. In 365 A.D. following an M 7.7 earthquake in Crete, a tsaunami caused extensive damage in Libya, Egypt, Calabria and as far as Spain. This tsunami is unique in the historical record, in that it is the only event of its kind known to have propagated across the entire Mediterranean without major attenuation of the sea waves.

Recorded tsunami heights exceeding 20m have reportedly been reached in the Eastern Mediterranean and the Messina earthquake (M71/2 – 1908) caused waves of 8.5m on the Sicilian and more than 10m on the Calabrian Coast, with the maximum height of 11.7m at S. Alessio washing up 200m inland. The Messina Straits and the eastern coastline of Sicily, especially around Catania, have an average of up to 10 tsunamis per 1,00 years. The last Tsunami recorded in this region was 1954 and a high probability exists for another tsunami disaster.

In the more exposed parts of the Mediterranean, for long coastlines, the return period for approximate run-up height of tsunami wave has been given at: (6)

100 years – 1.5m high
500 years – 4.0m high
1,000 years – 7.0m high

In 1960 an M8.5 earthquake in Queule Chile produced tsunami 15m-20m in height, with the debris extending 2 km into the interior. One must note that low lying areas exist to the foot of the mountain. It damaged residential quarters, a village 1.5km inland was flattened with 4.5m high waves, destroyed factories and sank ships.

In 1944 an M7.4 earthquake in Hawaii deposited large coral blocks of up to 1.3m across which had been torn loose in the sea, up to 5m above sea level. Many steel frame structures were damaged, the boilerhouse and powerhouse of a sugar mill collapsed, machinery, tanks and pipes were swept out of the building and a large tank was carried nearly 300m inland. One of the spans of a railway bridge in Hilo fared no better, it was carried 230m upstream.

In 1964, Crescent City, California, the third wave ran 1/2 km inland and the debris carried along smashed into structures at velocities up to nearly 40km/h.

In the Mediterranean, after the Algerian earthquake M6.8 of 1954, turbidity currents travelled at 50 to nearly 100km per hour on a slope of 1:150.

Overall large tsunamis are less frequent in the Mediterranean than in the Pacific Ocean. Most Mediterranean tsunami sources lie along mainland and island coastal regions, with tsunamis reaching local coasts soon after they have been generated, giving little time for warning. The strongest tsunamis are excited in the Aegean Sea and the Hellenic and Calabrian areas.

CONCLUSION

Subdividing The Maltese Islands For Earthquake Perils Exposure

There is a striking contrast between eastern and western Malta. There is a complete absence of Clays from the eastern two-thirds of Malta (Region A: see map of islands). Malta's dormant fault system is predominantly ENE-WSW. The Islands tilt to NE results in most valleys draining NE; a coastline of submergence on NE, with deep inlets and bays; high cliffs on SW.

Compared to Malta, Gozo shows a more varied geology, greater relief contrast and more extensive outcrops of Clays.

The major difference between Region A and other regions is that in the other regions, the rock is generally bare, except for the valleys, slopes and basins, whereas in this Region, it is rare to see bare rock, because of the soft Globigerina rock, which forms more quickly into soil. Another difference is the low altitude, most of it being below 90m and low-land dominate over the hills. The coastline is rather indented, with many headlands and bays, the principal one being the headland containing the Capital, Valletta and forming the Grand Harbour. The next important port is M'Xlokk again in the A Region in the southernmost part.

To be noted also is that buildings in the Inner Harbour Region, with a population density of 5,258 consists mainly of an old building stock, with building age exceeding 200 years not being uncommon. In Valletta, buildings in masonry of 8 storey height exist. The Outer Harbour Region consists of more recent construction, however building ages exceeding 80 years are not uncommon. In the outlying villages around the village core, an old building stock (of 2-3 storeys height) exists with ages varying from up to 80 years, with buildings constructed 200 years ago also encountered.

In the other regions, where a reduced population density exists the geology and relief has already been noted as being totally different from other regions. The existence of clay slopes are noticed although most of the constructions are away from the clay slopes. In Gozo, settlements occur on plateau tops founded on Upper Coralline Limestone. Care must be taken of perched settlements on plateau edges as minor rock falls occur in the earthquake intensity range of MSK V-VIII with massive rock falls occurring from the MSK VII upward range.

The long 136.7km shoreline of the Maltese Islands makes it susceptible to tsunami damage. From the Islands tilt to the NE, the most exposed areas are the sides facing Sicily, although deep valleys on the opposite face such as at Wied iz-Zurrieq and Xlendi may also receive damage. Damage is mostly to Beach Concessions and Port Works at sea-level, as where an escarpment of over 4m height exists, the risk is reduced.

The causes of Volcanism would again affect the shoreline facing Sicily, with the greater extent of damage in Region A, as it consists of the most exposed site with little relief features breaking up the topography. The extent of damage is dependent on the type of wind blowing during the eruption. As Malta lies NE from Sicily, this direction corresponds to the second most frequent Grigal wind, which blows violently for 10% of the year for about 3 days at a time mostly during March and September.

Each region presents its own perils. Region A may be more stable towards Earthquake loading, but then more susceptible to volcanic or tsunami damage.

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