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GEO-PHYSICAL FORCES AND ARCHITECTURE

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Abstract: Investigation was carried out to see the effect of natural forces, specially wind, rain and earthquake etc. on the Architecture of a region with special reference to Bangladesh. The buildings are subjected to great many different and often severe stresses during their lifetime. Some of these stresses are inherent in the structure, others ore imposed from outside. Natural forces are outside stresses imposed on the buildings. Nature of the geo-physical forces that may act upon the building have been reviewed. Relevant data is also collected from appropriate sources to evaluate and suggest required measures to tackle the situation.

Key words: Geo-physics; Climate; Architecture; Structure; Stresses

Introduction

One finds in the Earth a great variety of injustices and there is one, about which nobody ever speaks out but tries to compromise, the injustice of climate. The people of Bangladesh have moulded their livings in the light of the natural calamities. The geo-climate of a place not only decides to a great extent the nature of a man and his habit. Architecture, which has been evolved for his shelter, is also greatly affected by the natural forces.

Architecture is the product that takes its shape with the sun; the earth and the sky are the true materials out of which architecture is made (Mowla, 1985). Respecting the geo-climatic forces the traditional houses are being constructed in a way so that it can resist most of the common problems such as throwing out of much of the rainfall received during the storms, and can resist to some extent the shocks and settlement of earth. If these houses are destroyed, it will never destroy lives to the proportion it would have destroyed, had these been like the temporary houses built in the other types of geo-physical regions of the world.

Once constructed, the buildings are to stand in a great many different and sometimes many hostile stresses, during their lifetime. Some of them are imposed by the nature such as the load of wind, rainfall, tidal waves, earthquakes etc. Geo-physical data are much more useful and informative, from an architect's point of view, are the average of a particular variable. One must also be aware of the extremes of weather in the region. Further these extremes are useful only if they occur at regular and frequent intervals. Therefore a logical approach to the design and construction of structures would be to take into account these hostile forces and thus to create a safe and lasting architecture. Following sections discusses the various geo-physical forces that affect the design of buildings.

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Geo-Physical Forces and their effect in Buildings

1. Wind load: Generally, the pressure of air at rest is of no great interest to the architect except perhaps when one is installing a pump. On the other hand moving air exerts a certain amount of pressure which can be of enormous importance in the design of building. While designing a structure, wind is assumed to act on a horizontal direction which does not always happen, approximate angle of incidence may be assumed by the surrounding conditions and configurations of the structure.

The Map-1 shows the average of the maximum surface wind that can be expected in different places of Bangladesh. The values from Map-1 may be multiplied by six to get approximately the extreme values of the wind with which a place may be struck during severe storms. Since the pressure works against the house, Architects or Engineers are more interested in pound per square feet of pressure than the wind velocity in miles per hour (Table- 1 shows conversion from wind speed to pressure).

The speed of the peak gust should be considered in designing structures to withstand the onslaught of hurricanes. Another important consideration in relation to construction and hurricane damage is the rapid rise in the actual force of the wind at higher speeds, it can be expressed by the formula P=KV shown in Table-1.

The wind speed progressively increases with the height due to the gradual reduction in the frictional effect of earth, this can be seen from K.G. Mowla's wind curve. (Fig.-1) deduced and simplified from Ekman's spiral for relative wind velocity at different hights in the Northern Hemisphere. (Table- 2 approximately shows the same thing, taking wind speed at about 30-ft. height as 100%). Tall structures, as can be seen from the deductions and observations, have better cross ventilation with appropriate openings but at the same time they have to withstand much higher wind velocity.

In most zones of Bangladesh, a house designed to face a load generated by surface wind of 60 to 70 mph is strong enough. However, along the coastal belt, houses must expect to withstand winds of hurricane intensity. In fact buildings which were properly designed and constructed to withstand a wind load of 20 lb/sq. or wind speed of about 90 mph suffered no serious damage (Mowla, 1967, 1969).

Nature of Winds and the Damage: Hurricane winds passing over and round a building will develop both pushing (+ve) and pulling (-ve) forces. The United states Bureau of Standards (USBS) has shown that for all buildings the total force acting may be one and one-half or more times the direct pressure against the wind ward side of the buildings, due to the suction pressure on the lee side of the structure. For certain angles of incidences of the wind, the negative pressure may be considerably larger than the frontal force. In addition, the shape of a house will sometimes increase the force with which the wind strikes it. For a rectangular shaped house, for example, a shape factor of 33% must be added to the basic wind pressure.

A general type of damage by hurricane winds which occurs to buildings of one storey frame construction with peaked roofs is the removal of the roof. This is primarily due to inadequate anchorage of roofs to the wall. The positive and negative forces of the wind exploit every weak point. Almost all types of damage will permit water to enter the buildings, resulting in additional water damage. For a typical gable roof, the negative pressure on the wind ward side of the roof increases in a regular way as the pitch of the roof increases. At roof slope of 30 degrees and more, the wind pressure turns positive and increases as the pitch of the roof increases (Fig.- 2). As for walls of general construction, wind pressures acting on the down wind side of a house will be lesser, of course, it depends on the basic shape of the building. But it is the relative change in air

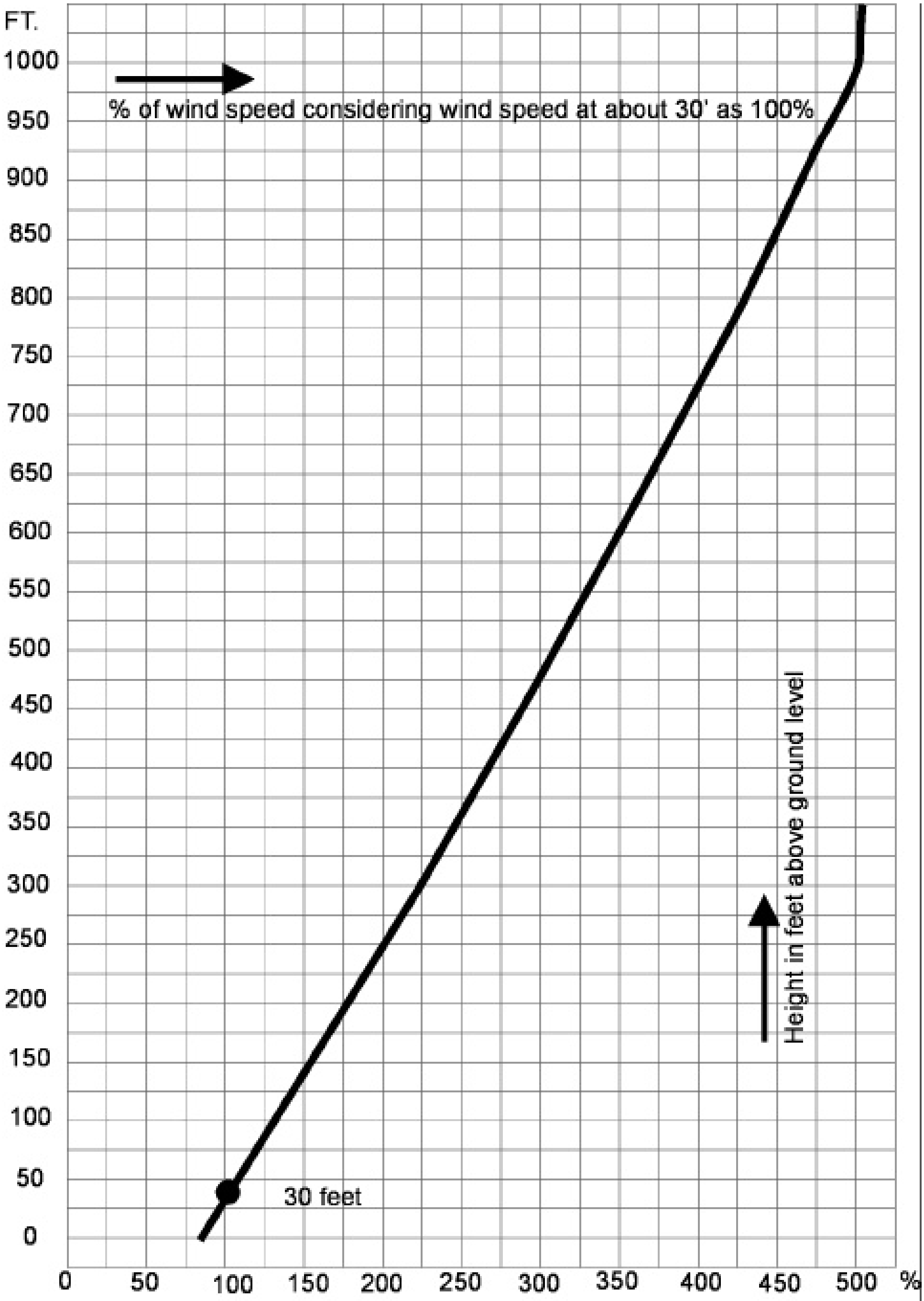


Fig.- 1. Mowla's wind curve, deduced and simplified from Ekman's spiral.

WIND SPEED (mph)-V	CONSTANT -K	PRESSURE (lb/s.ft.)-P	
15	.003	.675	$P=KV^2$
30	.003	2.7	
45	.0035	7.09	
60	.004	15	
80	.004	26	
100	.0045	45	
125	.005	78	
150	.005	112	
175	.0055	168	
225	.006	303	

Table- 1. Representative wind load suggested by gentry.

FT. ABOVE GR.	5	10	20	30	50	100	200	250	300
% OF WIND VEL. (Appr.)	70	90	95	100	110	125	145	155	170

Table- 2. Comparative wind velocity at different height.
Note : Intermediate values may be deduced by rule of three

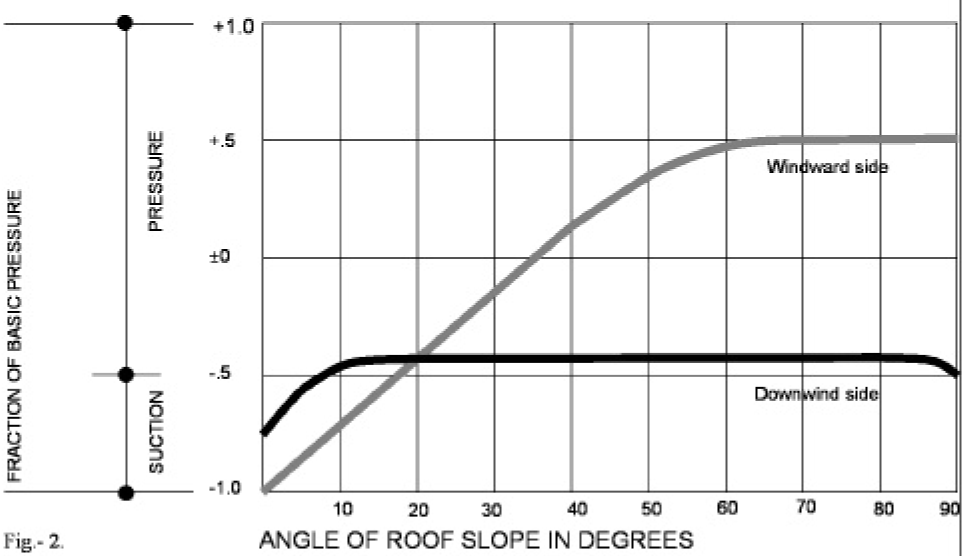
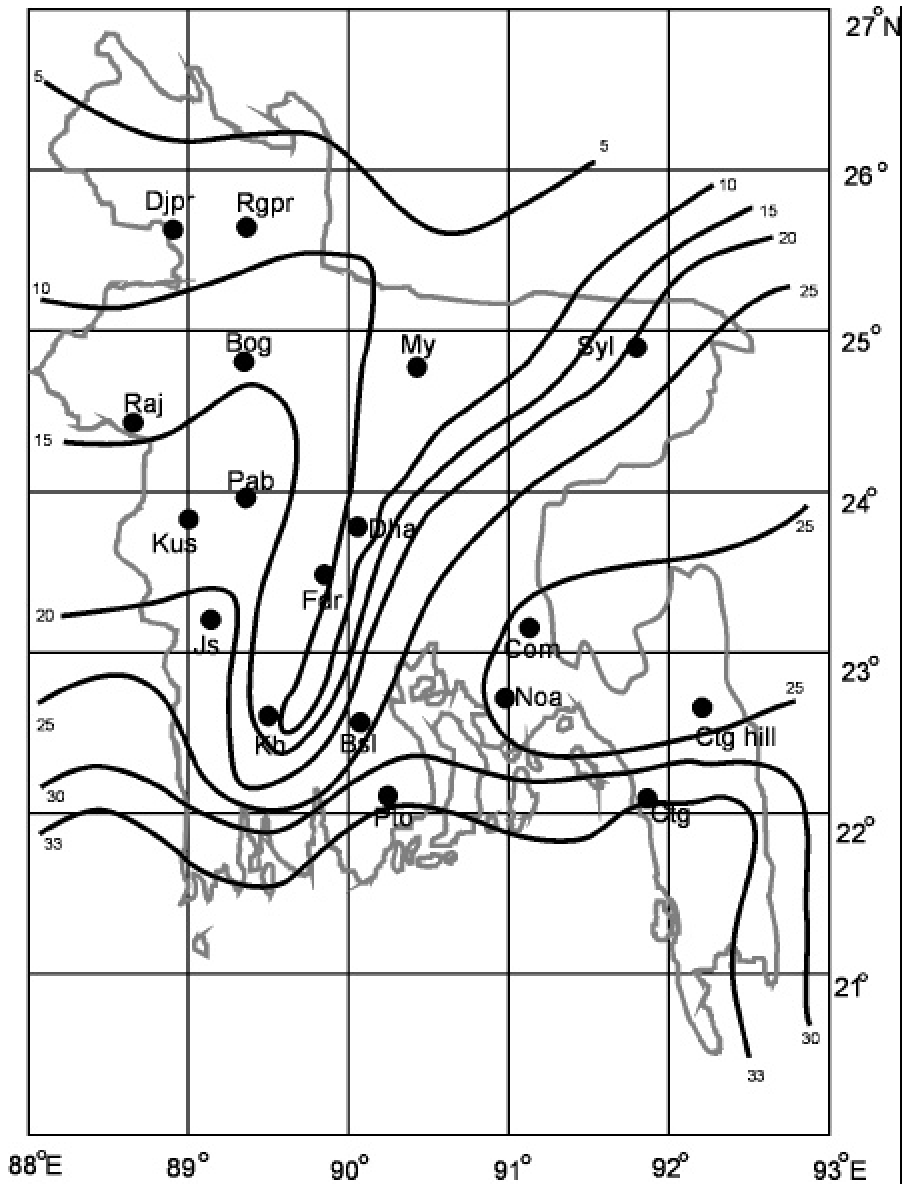
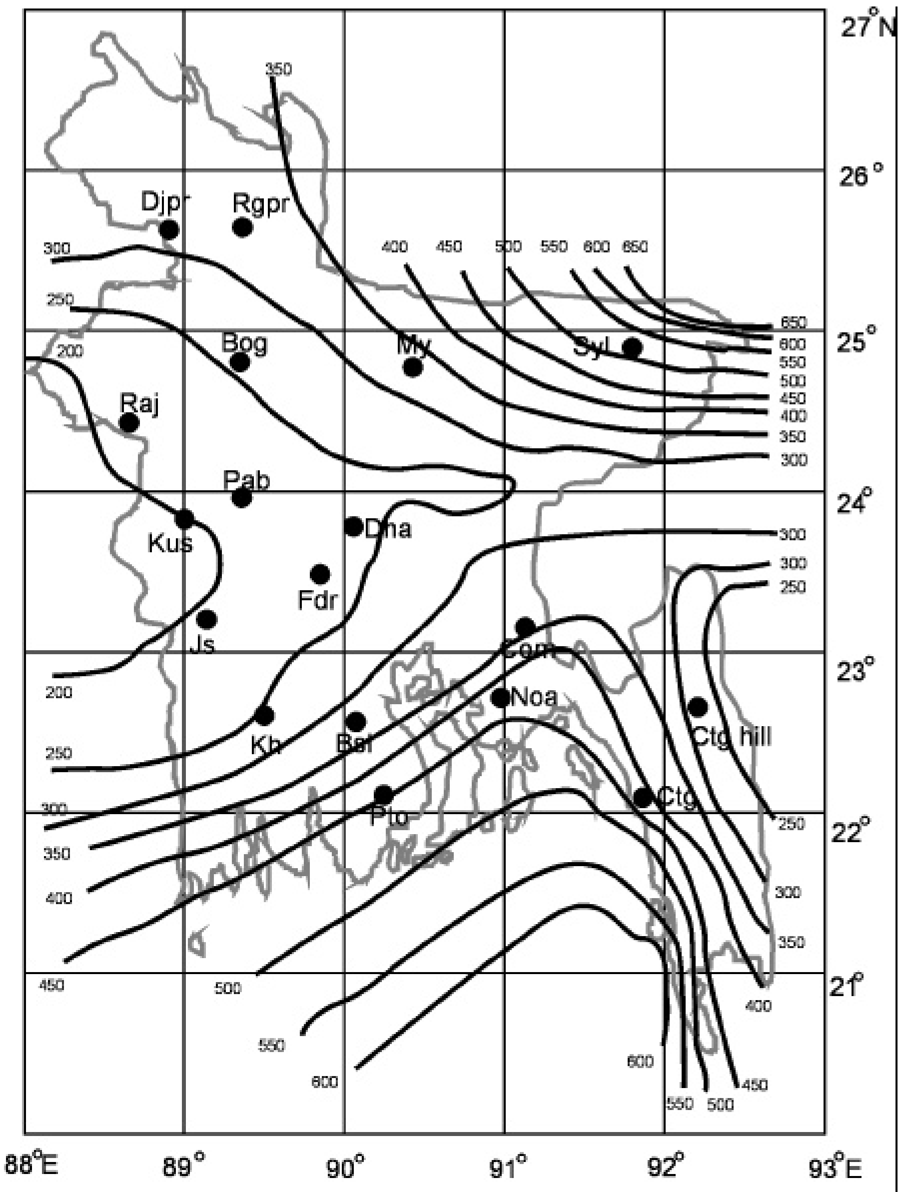


Fig.- 2.

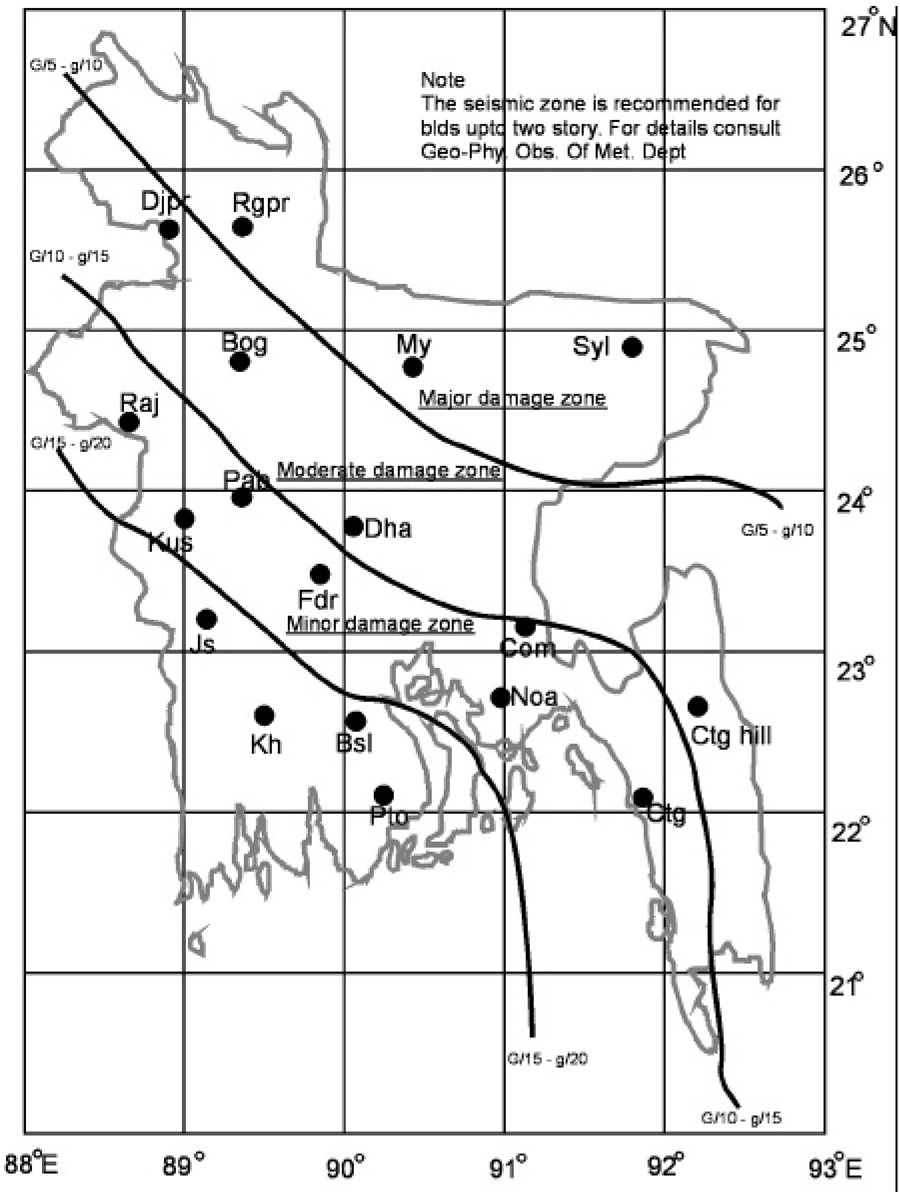
Note : The suction on the downwind side of the roof remains constant at about -0.5.



Map- 1. Isotech in M.P.H. (Average of maximum of the representative month July) in Bangladesh.
(Source: K.G. Mowla, Ex Director, Meteorological Services. Investigator: The Author)



Map- 2. Total Rainfall load in lb/s.ft. of surface during monsoon (June-sept.).
(Source: K.G. Mowla, Ex Director, Meteorological Services. Investigator : The Author.)



Map- 3. Seismic zones of Bangladesh ($g = 100\ cm/sec^2 = 32\ ft/sec^2$)
(Source: K.G. Mowla, Ex- Director, Meteorological Services. Investigator: The Author.)

pressure between inside and outside of the house that are responsible for shakes and rattles. Walls not properly designed (with adequate supports and ties) to resist both types of pressure are likely to be severely damaged.

Tornadoes are a special phenomenon of storms over an area with the radius of about a mile or less. It has in it a very strong wing rotating in cyclonic circulation, and creating a very low pressure at the centre. The wind speed inside tornado may vary from 200 mph (200 lb./sq.ft) to 400 mph (800 lb./sq.ft) and the pressure at the center may be reduced to $7/10^{th}$ of the normal surface pressure (Mowla, K.G., 1969). Such a decrease in pressure from the rim to the centre of the tornado represents a tremendous force, which few buildings can withstand. Unless extremely necessary (i.e. in the design of nuclear power installations etc.) no tornado proof structure is required to be built since it is not worthwhile due to the vanishingly small probability of a tornado to pass over a building. However precautionary measures may be taken in a building to prevent severe damages.

2. Tidal Bores: The hurricane tide alone may result in an havoc, but properly constructed and well-anchored buildings are usually able to withstand the rise in the water level. As a rule of thumb, heights of tides are $1/10^{th}$ of the value of wind speed and is expressed in feets i.e. at 100 mph wind, the tide would be 10 feet high. If the sea surges occur simultaneously with the high tides this would further the damage. Dun & Miller (1969) pointed out that "It is not probably ordinarily conceived how much energy is there in a tropical storm. An average cyclone squeeze about 20,000 million tons of water and this represents energy to 5,00,000 atomic bombs on Nagasaki type."

A cubic yard of water weighs about three forth of a ton, and the breaking wave which may be moving shore ward at speeds up to 50 mph to 70 mph is one of the most destructive elements connected with the hurricane. This is specially true when debris such as tree trunks, heavy beams etc. are picked up by the waves and used with pile driving effect which will wreck houses and even thick concrete installations in short order. High way buildings and sand dunes, upon which some coastal structures are built, are undermined very quickly.

All sea side resorts should therefore have proper zoning laws which will not permit structures to be built too close to the edge of the ocean or on sand dunes unless piling goes down to the rock. Naturally ordinary cottages in Bangladesh constructed out of timber or bamboo or G.I. sheet can not withstand such strong impact. But much of the losses can be minimized if a belt of deep-rooted vegetation is raised on the coastal area. Vegetation of strong and high trees along the coastal area will certainly receive the first impact of storm and surge and naturally the areas behind the vegetation area will feel much less the impact of storm (Mowla, 1986). Strong community buildings, which can stand impact of the wind speed of say 60-70 mph, can be constructed in each area to give protection to the people during the tidal bores.

3. Rainfall Loads: Rainfall is measured by the depth of the rain water received directly on a horizontal plane, which is then amplified according to fixed ratio into larger values of interest. For instance one cubic yards of fall weigh about ¾ of a ton. Rainfall load is calculated by the formula $F=5.2I$, where F is the load in pounds per square feet and I is rainfall in inches. To the architects, the terms 'slow steady rain and sudden downpour' carries considerable difference in meaning, even if the total fall is same because the density of rainfall affects the construction of drains, gutters, and spouting. The density or intensity of rainfall is expressed as the amount of rainfall per unit of time. The total rain water load for monsoon (June-Sept) is plotted in the Map - 2, the values derived from the Map - 2 may be divided by six to get the approximate value of heaviest fall in twenty-four hours for any place. The exact value of heaviest ever fall during twenty-four hours is shown in Table- 5 it may be mentioned here that the extremes of rainfall within a time period, say one day are of great interest to Architects and Engineers for the calculation of drainage loading due to stagnant water. Rainfall load map shows that architecture in the coastal belt requires relatively an extra precaution for quicker displacement of water from over and around the structure and enables it to withstand the water load (Table- 3) that has accidentally accumulated during at least twenty four hours.

On the basis of maximum rainfall in twenty four hours, Bangladesh may be divided into three major zones i.e. 1 Coastal Zone (Greater Noakhali, Chittagong, Chittagong Hill Tract, Barisal, Patuakhali etc.) 2. North Zone (Greater Sy lhet, Rangpur, Memensingh, Dinajpur, Rajshahi etc.) 3. Central Zone (Greater Comilla, Dhaka, Tangail, Faridpur, Pabna, Jessore, Khulan, Kushtia etc.) See Table- 4 .

4. Earthquake Loads: The Map-3 shows the zoning with relative intensity of earthquakes in Bangladesh. In the southeastern zone the damages from the earthquake is very negligible and hence requires no special precaution in the construction of buildings. In the next three consecutive zones, the probability of damage from the shock and vibration doubles as the zone goes northeast. The northeastern most zones are major to moderate damage zones with the hypocentres of most shocks at a depth of about 40km (25miles) and more. All the hilly places of Bangladesh fall within these two zones where, in addition to earthquake shocks, many incidences of landslide and settlement of hills are observed. Therefore, extreme precaution should be taken in the construction in these areas. Piling should go down to the rock while constructing in these places.

There are a number of points to be considered in the design for the prevention of earthquake damages such as the geological data, shape and size of the structures, method and material of construction etc. but these are beyond the scope of general discussion in this paper. The seismic factor shown as fraction of “g’ in the isoacceleration line over the Map 3 is recommended for buildings up to two or three story. For higher buildings or projects of national importance, Geophysical Observatory of Bangladesh Meteorological Department may supply the needful seismic data of the location.

Earthquake loads are similar to that of wind load but are much shorter and sharper. A wooden or R.C.C structure designed to stand in its inertia of relative rest under a wind load of 15-20 lb/sq.ft is thought to have the capability of withstanding most earthquakes. But masonry does not have such resilience under sudden sharp loading. Entire masonry may collapse during severe shocks. Even under moderate shocks it is likely to suffer some damage. In the major damage zone the masonry buildings may be avoided or must be specially reinforced to resist sudden horizontal jolt.

Recommendations and Conclusion

Although throughout the preceding discussion, few on the spot precautionary measures are suggested yet a few more tips, that are hoped to be of help in the resistance of the discussed geo-physical hostilities, are proposed. At first the government should have zoning laws and thus compel the execution of the prescribed precautionary measures in the design and construction. Sound construction and planning should include consideration of the following:

1. Coastal areas should have extensive embankments vegetation or protective devices such as high and strong bulkheads and sea walls and jetties to be built where needed to reduce destruction of hurricanes and tidal surges
2. To provide proper size and reinforcement of foundations and piers.
3. To give adequate connections between foundation and sills.
4. To anchor roof and ceiling framing to sidewalls. Broad roof overhangs, which permit the wind to get under and to lift them up, may lead to trouble. A hipped roof with about a 30° pitch is

about ideal. Flat roof is undesirable unless special treatments are made. Roof surfaces should be inspected once a year just before the hurricane and monsoon season and repaired when necessary.

5. Secure attachment of roof coverings and sidings.

6. Concrete and masonry –block strength should be checked.

7. Provisions for vertical columns and tie beams for hollow wall structures may be made.

8. Provision for plate-attachment bolts or roof and ceiling joist anchors in the pouring of tie beams in the exterior masonry walls.

9. Install shutters to cover glass windows.

10. Be sure that window or door can be partially opened on the lee side of the house this will keep pressures on the out side and the inside equalized. Without such equalizations, higher indoor pressure during storm may become strong enough to force doors and windows open. Walls, doors, windows or where ever possible there may be such designed weatherproof gaps, which will facilitate quick equilibrium of pressure in and outside the structure. Some weatherproof weak points may also be kept, where applicable. To allow the explosion through them during very heavy difference of pressure particularly during a tornado and thus save the building itself.

11. In a country like Bangladesh with so heavy rainfall, a pitched roof is perhaps the best type. One with an ideal slope of about 30 degree to protect the interior space from rainwater.

12. In case of flat roof, adequate spouts would facilitate the quick disposal of rainwater. It is observed that sometimes during heavy rainy storms, leaves and other refuse clog the rain drain spouts in the roof which accelerate the accumulation of water on the roof. Roofs are normally designed to support a live load of about 20 lb./sq.ft. where as each inch of rain water per square feet weigh about 5.2 lbs. Therefore more than 3.5 inches of stagnant water cannot be allowed over the roof and hence openings may be designed in the parapet at about 3 inches above the roof top for the over flow of accidentally accumulated water.

13. All other damp proofing precautions in the design and construction are also necessary in all parts of Bangladesh.

14. Minimum lateral seismic stresses should be considered in the design of all earthquake resistant structures and again that should be assumed to act diversified in the direction of each of the main axes of the structure.

15. For major seismic damage zone, the geotechnical experts should be consulted for the evaluation of the site in terms of any of the following earthquake hazards: active faults in the site, the probability of liquification of the foundation soil, and landslides. Site should be declared unsafe for construction in the presence of any of the above mentioned hazards. The seismic report may recommend the acceleration for which the structures should be designed, in the absence of data for land sliding, faulting, or expected subsiding for the site.

16. Timber construction is most suitable for earthquake prone areas. Well-designed R.C.C. is also a modern substitute to a large extent to timber structures, in resisting shocks. In masonry constructions R.C.C. rings may be placed at different levels i.e. at foundation, at lintel and at roof levels, and to have adequate ties between them to resist the uneven settlement and jolts by the tremor.

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