Ways to Protect Existing Buildings with Low-Cost Methods to Deal with Environmental Changes

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Abstract. Different methods are used to reinforce existing buildings to cope with more frequent extreme weather. As the frequency of extreme weather increases, the requirements for wind resistance, flood resistance and resistance to other natural disasters required by buildings have also increased. This is usually accompanied by the increase in construction costs and most of the existing buildings do not have the disaster resistance of new buildings. The proposed need to strengthen existing buildings to reduce costs and deal with disasters. In the following paragraphs, different reinforcement methods have been proposed for different natural disasters, such as wind disasters and floods, and verified by testing the physical structure resistance. The conclusion proves that the wind resistance and flood resistance of existing buildings can be improved through relatively inexpensive additional simple structures.

1. Introduction:
This paper mainly discusses how to make existing buildings adapt to potential climate threats through a more general and low-cost method under the conditions of global warming and increasing days of extreme weather. In the year of 1979, the First World Climate Conference was held in Geneva. That was also the first time that the theory of global warming was formally put forward, on Climate Change (IPCC) in 1988, the issue of global warming has been recognized more and more widely and attracted the attention of the governments. “Global warming generally is expected to increase the magnitude and frequency of extreme precipitation events”[1]which means that buildings are more likely to have the ability to face flood threats, especially for buildings along rivers and in coastal cities. To study the damage caused by wind and water to buildings, additional structures that can be used to improve the resistance of buildings in the face of wind and flood disasters will be discussed. These structures are usually simple to construct and less expensive. In view of the increasingly severe extreme weather and the need to spend huge amounts of money to upgrade the building's wind and flood resistance, a simple, efficient and less costly disaster resistance improvement method is very urgent at this time.

Not only is there potential frequent flooding, but the climate change brought about by global warming will also affect another item that will cause damage to buildings and force future building standards changes. That is the wind. A study published in the journal Nature Climate Change finds that winds across much of North America, Europe and Asia have been growing faster since about 2010, the global average wind speed has increased from about 7 mph to about 7.4 mph. Although this is a good news for renewable energy production, it will produce more damage to buildings for certain. Long-term high-speed wind will cause long-term safety hazards to buildings, especially skyscrapers in cities. At the same time, it will also place higher requirements on the design and construction of buildings, which means more costs of constructions.
It is important to find ways to adapt to extreme weather for existing buildings as researched in this paper.

2. Effects on architecture/civil engineering.
More and more frequent floods and rising sea levels caused by global warming will make buildings along rivers and coastal cities have to face a series of challenges. When designing a building, an architect must consider the potential flood threats that the building may encounter. From another perspective, it will bring more restrictions and challenges to the design of the building. The foundation of the building may need additional reinforcement, the waterproof design of the ground part needs to be considered, and the resistance of the building after being soaked in water. During the construction process, precise waterproof treatment and requirements for construction technology will also become higher due to the threat of floods. This influence is not only reflected in the design of a single building, but also in the design of the civil engineering of the entire city. The heavy rainfall brought about by climate change will put forward higher requirements for the overall flood prevention design of the city. Urban drainage systems need to consider the impression of heavy rainfall factors more to avoid waterlogging, and the design of roads also needs to consider rainfall factors.

When it comes to the problems of increasing wind speed, the situation can get even worse. The high-wind performance of office building envelopes has historically been poor. In large part, the poor performance is due to inadequate design attention. Even a well-designed, built, and maintained building can be damaged by wind disasters that are much stronger than the original architectural design. Changes in wind speed caused by climate change mean that most existing buildings will be more likely to be damaged by stronger winds than they were originally designed. Various winds such as straight wind (the most common type), downhill wind, etc., have strict requirements on the design of new buildings and the reinforcement of existing buildings. Not only need to consider the damage to the building caused by the wind itself, but also consider various wind-induced damages, including wind-driven rainwater penetration, etc.

3. Problems of New Standards.
In order to preventing potential damage caused by flood, the Federal Emergency Management Agency set standards of flood damage-resistant materials requirements and also provides construction examples:

![Building elevated on solid foundation walls meeting the minimum NFIP requirements](image-url)
Figure 1 illustrates a solid foundation wall (crawl space) elevated to meet the minimum requirement that the lowest floor be at the BFE.

These two figures above show exactly how complicated it would be for a building to meet the requirement of flood damage-resistant. The new standards require buildings to meet requirements that are much more various in different aspects, not only in the selection of external wall materials, but also in the overall structure of the building and the control of the building's internal pressure and so on. Besides these, the selection of different materials and structures will also significantly affect other building requirements, such as the need for indoor fire protection and higher requirements for exterior decoration. This will bring much greater challenges to the design of new buildings. From another perspective, in order to achieve new flood and wind resistance standards, it not only requires people to spend more resources, not just money, on designing and constructing to meet the new standards. In addition, it is necessary to demolish existing buildings that cannot meet the new standards for the construction of new buildings to deal with the potential threats posed by climate change. These expenses are almost no one or any of the government can afford. At this time, a more urgent method is needed to strengthen existing buildings to increase their resistance to floods and wind disasters. This will be more feasible in terms of funding and time.

4. Potential Ways to Reinforce existing buildings.

4.1. Reinforcement gives buildings stronger water-resistant
This section includes:
1 Problems faced by buildings that are close the sea to withstand lateral loads caused by the tsunami and possible materials that can be used
2 Simple and cost-effective solution -- tie beams structure

4.1.1. Possible materials that can be used.
Buildings that are located on the coast and floods in low-lying areas usually face the threat of tsunami and water intrusion. In order to do that, one of the feasible ways is to strengthen the outer wall. There are several typical materials that can easily be used for houses to provide additional water-resistant:

Burnt clay bricks, which is recommended by Jayasinghe[4], are good quality bricks are used with 1:5 cement: sand mortar. It can be applied in construction with a minimum dimension of 200mm
length × 100mm width × 50mm height. With the 1:5 cement: sand ratio, burnt clay bricks have a compressive strength of 21.5 Nmm⁻².

Cement sand block is another material that could be used as a reinforcement. Its advantage lies in the more modular size. The solid thickness is usually 100mm, 150mm or 200mm hollow thickness. These existing sizes can be adapted for different reinforcement requirements, but usually considering the weight issue, solid cement sand blocks are usually limited to a thickness of 100mm. The cement sand solid blocks indicated wall strength of about 20.8 Nmm⁻², which is slightly weaker than burnt clay bricks.

Another advantage of these two materials is that they are both very cheap, in average from 1 dollar to 3 dollar each.

Table 1. Enhancement of lateral load carrying capacities for different walling materials when tie beams are provided at lintel and window sill levels[4]

| Type of Walling material | Characteristic compressive Strength kNm⁻² | Maximum wind load that the wall can carry kNm⁻² |
|--------------------------|------------------------------------------|---------------------------------------------|
| FS                       | LL                                       | ASL                                        |
| Standards Clay Bricks    | 225                                      | 1.5                                        | 0.172 0.698 2.103 10.179 |
| Non-Standards Clay Bricks| 225                                      | 1.0                                        | 0.160 0.686 1.929 7.551 |
| Cement sand hollow blocks| 100                                      | 1.2                                        | 0.069 0.293 0.729 2.434 |
| Type 2                    | 200                                      | 1.2                                        | 0.142 0.599 1.614 6.286 |

FS-Wall behave as a free standing wall
LL-Above lintel level
ASL-Above window sill level
BSL-Below window sill level

4.1.2. Simple and cost-effective solution -- tie beams structure.
Finding the appropriate low-cost materials isn’t enough. It is also very important to know how to use these materials to reinforce the outer wall to prevent damages caused by water.

Since this section discusses how to reinforce those existing buildings, apparently it is needed to have additional structure or constructions out of the original one in order to achieve the goal. The easiest way to do so for a residence or a simple wave wall built for any building can help the building resist part of the tsunami or water immersion threat.

When applying materials like burnt clay bricks and cement sand block, the tie beams in walls can enhance in-plane and lateral resistance.
This tie beam structure has been applied already in many places. The 1:5 cement sand mortar is a common material used in construction in Sri Lanka. The tie beam structure will “be able to resist disintegration due to liquefaction of sandy soils that occur in a Tsunami situation when the structure is located close to the sea coast on sandy soils. It can also give some flexural capacity that may be helpful in resisting any minor movements that may occur when flood situations saturate and weaken the soil underlying the foundation”[4]. The lateral force exerted by tsunamis and floods on buildings or wave-resistant walls will depend on the height of the water level and the speed of water flow. The window or the opening on the outer wall is usually a source of weakness for lateral and in-plane load carrying capacity. In order to reinforce that part, it is recommended to apply three tie beams plinth level, window sill level and above the openings have the potential to improve both lateral and in-plane load carrying capacity of masonry walls used in single or multi story houses as shown in figure 4:

4.2. Reinforcement gives buildings stronger wind-resistant

4.2.1 Different wind types.
- Straight-line wind. This type of wind event is the most common. The speed range of this type of wind can vary from very low to over 165 mph.
- Down-slope wind. Wind flowing down the slope of mountains is referred to as down-slope wind. For mountainous areas are referred to as "special wind regions", and ASCE has special requirements for the minimum design load of buildings in those areas.
- Thunderstorm. This type of storm can rapidly form and produce high wind speeds.
- Downburst. Also known as microburst, it is a powerful downdraft associated with a thunderstorm.
- Hurricane. This is a system of spiraling winds converging with increasing speed toward the storm's center. Hurricanes have the greatest potential for devastating a very large geographical area and, hence, affect great numbers of people.
- Tornado, a violently rotating column of air extending from the base of a thunderstorm to the ground.

These different winds are spread all over the world, which means that different regions are facing different types of wind disasters. But the following method can be regarded as a general solution to relatively lower intensity wind disasters

4.2.2 Evaluating Office Buildings For Risk From High Winds.
Evaluating office buildings for risk from high winds is an important step to understand what potential damage could be done to a building. First step is to determine the wind speed from ASCE 7. If the basic wind speed reaches over 90 mph, the risk of damage increases and construction and maintenance enhancements are recommended. Second step, for office buildings not located in hurricane-prone regions, determine if the office building will be used for emergency response after a storm. This helps to determine the capacity of the building needed in order to serve the purpose of emergency response. Third step, for office buildings in hurricane-prone regions, determine if the office building will be used for a hurricane shelter or for emergency response after a storm. If so, construction and maintenance enhancements are recommended[6].

4.2.3 Reinforcement.
It is harder to reinforce an office building to improve its wind-resistant capacity without redesigning the outer wall of the building. One of the ways is to adjust the pressure of the building. The wind hitting the outer wall exerts a positive pressure on the wall, forcing air to enter the building through the opening, while the windward wall is under positive pressure, the side walls and rear wall are under negative pressure. When the building is decompressed, the internal pressure will pull the roof so as to reduce the amount of bulge imposed on the roof. The reduced internal pressure will also pull inward on the windward wall, which will increase the wind load on that wall.

![Figure 5. Schematic of internal pressure conditions with different dominant opening [6]](image)

Modern buildings, especially office buildings, usually have higher requirements for communications and other aspects, so their roofs usually contain different electronic components and
ventilation equipment, etc. These irregular protrusions are usually the most susceptible to extreme wind speeds. And these irregular protrusions and the irregular shape of the part near the roof of the building itself usually affect the wind resistance of the whole building. In order to solve this problem, buildings facing wind damage can enhance the wind resistance of the building by integrating the roof shape. In addition, the steel or wooden sheath (plywood or oriented strand board) of the building needs to be connected with screws, because the screws are more reliable and less susceptible to solve problems.

Figure 6. Pressure on different roof shapes [6]

5. Conclusion.
The more frequent extreme weather caused by climate change requires people to implement new building standards as soon as possible to ensure safety, but before they can be fully converted to the new standards, different existing building reinforcement technologies are bound to ensure that most of the existing buildings. The building can cope with natural disasters beyond the original design. At the same time, it can save the use of resources which protect the earth environment as well.

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