On behalf of:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

of the Federal Republic of Germany

Climate-Resilient Buildings

A brief from the Integrated Climate Change Adaptation Strategies (ICCAS) Pilot Programme

Challenges

Grenada, a small island developing state (SIDS), is especially vulnerable to the negative effects of climate change. As the climate changes, the construction industry in Grenada should be aware of its potential impacts and make changes in the construction culture to reduce these impacts. The most prominent effects of climate change include: an increase in extreme weather events (i.e. more destructive hurricanes and droughts); more frequent and intense heat waves; heavier rainfall events leading to flooding and landslides; rising sea level and increased coastal flooding. There is also an increase in direct and indirect climate impacts on human health such a vector-borne and respiratory diseases. It is imperative that the construction industry in Grenada considers designs geared towards coping with climate change impacts.

Climate change refers to significant changes in global temperature, precipitation, wind patterns and other measures of climate that occur over several decades or longer.

Climate Change Impacts	Climate-Smart Design and Build Solution
Floods and land slippage	• Avoid building in flood prone areas • Raise buildings above the ground • Provide adequate drainage and storm water conveyance for building and land safety. Eliminate mosquitoes' breeding sites and the risk of leptospirosis
Sea level rise	• Take into account the projections for sea level rise when building • Raise ground floor structure to at least 3ft above the predicted high tide level • Use materials and a concrete mix that are resistant to saline conditions
Stronger and more destructive tropical storms	• Foundation designs should take into account extreme events, deep foundations are more appropriate • More in-depth soil and slope analysis • Use slope stabilisation techniques • Minimum loads, including wind loads, used in designing elements should be based on loads prescribed by the OECS Building Code 2015 • Use recommended concrete cover as in table 16.3 of the OECS Building Code 2015 • Do not use beach sand as the saline content affects the integrity of the building • The connections of cladding/sheeting to the truss are to be designed for the increased forces, especially at the corners and the roof edges which are considered as zones of higher local wind suctions – Other solutions include the use of screws instead of nails and adding hurricane straps to secure the roof. Concrete roofs are more storm resistant than pitch roofs. • Create a continuous load path to allow for the transmission of load from any level down to the foundation
Higher temperatures	• Reduce concrete temperature and water evaporation by paying proper attention to ingredients, production methods, handling, placing, protection and curing • Provide for proper cooling techniques, including the use of natural/passive cooling techniques

Building in vulnerable areas

Flood prone areas

Building in flood prone zones should be avoided. Buildings located on a river bed, close to running water, will be vulnerable to flooding. Not only the building structure, but also its contents are vulnerable to destruction due to heavy rains. Houses should not be built in such obviously vulnerable locations, or if they are, they should be designed to be resistant to the hazards of their location. In Grenada there are known flood prone areas. A full map of the flood prone areas is available at the Land-Use Division at the Ministry of Agriculture and Lands.

Fig 1 - River Road, St George during the August 2018 flash floods

Flood zones are expanding, therefore hydraulic analysis and design should consider designs for less probable return event. This means that a watershed analysis should consider from a 100-year flood up to 500-year flood events. There is a greater need to complete models of both the micro and macro level of the area being considered. The area can be mapped and analysed to determine the existence of invisible course ways with the aid of civil engineers or land surveyors. This information should also be used for drainage design. More intense storms will compromise the capacity of standard storm water management infrastructure in some areas. These analyses will provide more adequate storm water conveyance.

The storm water conveyance should be considered on both the micro- and macro- levels. On the micro level, this would include the immediate surroundings of the structures being built, the conveyance for the structure itself (rainwater guttering) and even retaining walls. All retaining walls should be drained[1], the absence of drains will allow for the accumulation of water and the development of hydrostatic pressure. This hydrostatic pressure could cause the failure in retaining walls. On the macro level, emphasis should be placed on the properties above and below the ones being considered. The absence of this would lead to uncontrolled water runoff being present.

Land slippage

The effect of uncontrolled surface runoff includes destabilisation of the slopes, which may in turn lead to mass movement or landslides, as well as negatively affecting the buildings' foundation. A watershed analysis may be used to highlight areas where flooding may be possible and therefore avoided. In those areas buildings should be raised above the ground. Ground beams and slabs should therefore be designed as suspended elements. In flood-prone areas—even where flooding is only remotely possible—raise the buildings or living spaces above ground level to minimize any damage in the event of flooding. The mountainous topography of Grenada could be an asset in this venture and excess excavation could be avoided.

Coastal zones: rising sea level and coastal erosion

Any designs close to the shorelines should take into account the projections for sea level rise as well as stronger storm surges due to climate change. Predicted wave heights and wave energy shall be based on forecast design wind speeds in conjunction with the latest Caribbean Basin wind hazard maps. Non-elevated buildings close to the shoreline are most vulnerable to damage by wave action. In such locations, the ground floor structure shall be at least 3ft above the predicted high tide level.

Coastal zones are also prone to erosion, which could be caused by sea level rise but also by human activities such as the removal of mangroves and/or sand mining.

When building near to the sea, the appropriate flood prone mitigation techniques should be considered and the building should be built according to the regulations pertaining to the high water mark. As per the OECS Building Code 2015 *"No Building shall be erected on a site which cannot be put into such a condition as to prevent any harmful effect to the building or to its occupants by storm or flood waters."* There is also the high risk of the corrosive environment affecting the structure. The materials used should be able to withstand the saline conditions. The concrete mix should adhere to the established specifications for this environment.

[1] Drainage measure for walls consist of using free-draining material at the back face of the wall (Granular material should be preferred in backfilling), with "weep holes" and or longitudinal collector drains along the back face.

Designing buildings that are more resilient

Constructing a more resilient building starts at the design stage and continues through to the construction and must be maintained during the lifespan of the building. All building designs should be reviewed by the Physical Planning Unit of Grenada. Monitoring should be conducted during the construction stage to avoid deviation from the approved design.

The minimum loads used in designing elements should be based on loads prescribed by the OECS Building Code 2015 or any updates to this code. The designs should ensure a continuous load path for the structure, by guaranteeing that there are proper connections between the elements. This may be done by employing hurricane straps for roofs, proper anchorage and laps of reinforcement, and should also be verified during the construction phase.

In structures where concrete is being used, the designers and contractors should ensure that the recommended concrete covers, as outlined in **Table 16-3 of the OECS Building Code**, are utilised. Beach sand should never be used in concrete mixtures, since the saline content negatively affects the strength and life span of the reinforced concrete, thereby affecting the integrity of the building. During the building of the project, the formwork should be cleaned and deleterious material should be removed prior to pouring the concrete. Reinforced concrete exposed to brackish water, seawater, or spray should use a water cement ratio of 0.40 to protect the structure from corrosion.

Poorly mixed concrete will adversely affect its strength and durability. On hot days (temperatures in excess of 29 degrees C), steps should be taken to reduce the concrete temperature and water evaporation by paying proper attention to ingredients, production methods, handling, placing, protection and curing.

The connections of cladding/sheeting to the truss need to be designed for the increased storm forces, especially at the corners and the roof edges considered as zones of higher local wind suctions. Failure at any one of these locations could lead progressively to complete roof failure. It is also possible to use hurricane shutters or hurricane resistant windows. However, in some cases, this might be too costly for clients and therefore it is possible to revert to recommending preparing plywood shutters to protect openings as and when needed.

Foundations

The purpose of the foundation of the building is to receive the loads that are transmitted from the members (column, beams, load bearing walls, etc.) above and transmit these loads into the soil. There are many factors which influence the design of the foundation, this includes the members above and the wind loads that the building may be exposed to. The region has seen in recent years an increase in the intensity of hurricanes. Hurricanes and extreme events can increase the lateral loads on structures.

Foundation designs in Grenada should account for these extreme events. As such, there will undoubtedly be a need more in-depth soil and slope analyses. The soil analysis would highlight the characteristics of the soil and give insight into its bearing capacity (ability to carry load). This information would also fill into determining the stability of the slope and the possible need to improve the soil in the area and or employ slope stabilizing techniques. The use of proper foundation designs will eliminate settling over time. Foundations should be sized relative to the design loads that a structure is expected to exert on the ground. Soil strengthening techniques can be employed to achieve the required bearing capacities in areas where the ground is soft to great depths.

The OECS Building Code June 2015, highlights the following methods for slope stabilization: "Designers shall use appropriate methods of stabilizing existing slopes and creating stable configurations for new slopes:

*"**Geometrical** a) The construction of a retaining wall designed for the height and nature of the retained material. Drainage of the retained material is an important contributor to stability; b) Removal of material from the top of the slope; c) Terracing or cutting benches on the slope incline; d) Adding the weight of a soil or rock berm at the base of the slope.*

***Mechanical** a) Installing ground anchors or use of soil nailing; b) Plastic geo-grids placed on the slope surface to increase its bearing capacity; c) Concrete sprayed onto the slope; d) Planting drought resistant, native species of vegetation."*

Deep foundations are less vulnerable to destabilization by changes in rainfall patterns and ground water levels. Wherever possible, deep foundations should be employed.

A common climate change mitigation strategy is to re-use existing foundations, and to build on sites where there has previously been human activity (building, agriculture, industrial, etc.) – in preference to 'green field sites'. In such cases, an investigation of possible contaminants in the ground should be done and provisions for their safe containment. If a new building is erected in place of an old one, then one should ensure that the load bearing capacity of its foundations are sufficient to carry the new building design.

Design Loads

Loads generally used in designs are: dead load; live or temporary load; live roof load; wind load; earthquake load; rainwater load and hydraulic loads from soil. Due to the negative impacts of climate change, wind loads may have the greatest impact on future designs. This impact is attributed to the strengthening of hurricanes being formed in the Atlantic. The OECS building code has based its wind load provisions on the American Society of Civil Engineers (ASCE) "Minimum Design Loads for Buildings and Other Structures" ASCE 7-10. When using ASCE 7-10 a minimum wind speed of 154 miles/ hr shall be adopted for the Basic Wind Speed for Category II Buildings, while a wind speed of 168 miles/hour shall be used for Category III[2] and IV[3] Buildings. **Note:** In order to take into account climate change, all of the wind speeds listed shall be increased by factors of: (i) 1.13 for most buildings (= factor of 1.28 for pressures) (ii) 1.10 for critical facilities or for Category III and IV Buildings when using ASCE 7 (= factor of 1.21 for pressures). No matter the material used for construction, it is important that a continuous load path is created. This will allow for the transmission of load from any level down to the foundation. This may be accomplished by using hurricane straps at the roof level; adequate anchorage and lap lengths for reinforcement; correctly sized nuts and bolts and adequately sized members, and other methods. **Failure to develop fully functional load paths will result in the creation of weak points in the structure and its failure.**

Foundation must resist

- Dead Load
  - Weight of building
- Live Load
  - Weight of Occupants
  - Weight of Furniture
  - Weight of Equipments
- Lateral Load
  - Wind
  - Seismic

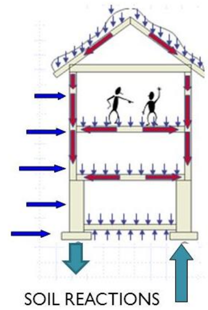

Fig 1 – Load transmission in structure

Fig 2 – Load path failure

Healthier buildings

Climate change also had a proven negative impact on human health. Specifically, the following impacts are to be considered when building in Grenada:

- Adequate ventilation could reduce the impact of climate change on respiratory diseases (see "passive cooling" in "Energy and Water Efficient Buildings for Climate Resilience" factsheet),
- Increased temperature can particularly have a negative impact on small children and the elderly. Cooling strategies should be considered during the design phase of the buildings,
- Climate change also comes with an increase in vector borne diseases. It is important to avoid ponding areas which are mosquito breeding sites with proper drainage and excavations. The importance of drainage is also relevant to the increase of leptospirosis, which is due to rats and floods.

Recommended Reading

- ✓ OECS Building Code of 2015 - https://www.oecs.org/sdu-resources/oecs-building-code-1-5
- ✓ "Disaster Preparation and Home Construction" by Curtis M. Jacobs 2013
- ✓ "Dynamics of Urban St. George's" by Norris Mitchell

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[2] Category III - Buildings and other structures that represent a substantial hazard to human life in the event of failure (primary occupancy is public assembly with an occupant load greater than 300)

[3] Buildings and other structures designated as essential facilities (Fire, rescue, ambulance and police stations)