LANDSLIDES

type of hazard in addition to the minimum requirements for Hazard Resilience given in Section B.

General Information

Landslides include a wide range of ground movement down a slope involving massive volumes of rock, soil, or debris. They can occur in a matter of seconds without any warning or over a prolonged period with or without some indications. The impact of a landslide may be limited to a small area or may spread over a large area. Ground instability can also occur suddenly or over a long period of time in the form of sinkholes, ground subsidence and ground movements e.g. due to formation of underground cavities and collapse or movement of material above. Land formation is the result of a continuing natural process of ground movements due to gradual weakening of rock and soil strata and the destabilized material moving down the slopes. For this fact, hilly areas are generally susceptible to landslides. The potential of landslides at a given location depends on many causative and contributive factors including geomorphological and physical features of the location.

Ten districts, viz., Badulla, Galle, Hambantota, Kalutara, Kandy, Kegalle, Matale, Matara, Nuwara Eliya and Ratnapura in Sri Lanka are identified as some of the districts having terrain prone to landslides (refer Map 1:

Landslide Hazard Prone Map of Sri Lanka with Reference to Locations) in Section A. Certain hilly parts of these districts may have a very high potential whereas some parts with gentle slopes or flat terrain can have a very low potential of landslides. Declaration of only the above ten districts does not rule out potential of landslides in any location outside these districts.

Knowing about the potential of landslides occurring in your area would help significantly in deciding a suitable location for building your house and what additional precautions that would be necessary to make it resilient to landslides

1.2 Planning Considerations When planning to build a house in a hilly area or on or nearby slopes, due attention must be given to the following requirements and conditions in addition to the minimum requirements given in Section B. Important! No construction is permitted on lands with ground slope > 31º unless clearance is obtained from NBRO and construction is done based on the recommendations and conditions given in the Risk Assessment Report. For ground slopes between 11º – 31º recommendations provided in this Section shall be followed (refer Table C-1).

1.2.1. Landslide Clearance for Construction SECTION C No construction is permitted on lands with ground slope > 31º unless risk assessment is obtained from NBRO and construction is done based on the recommendations and conditions given in the Risk assessment report. For ground slopes between 11º – 31º recommendations provided in this section shall be followed (refer Table C-1). Therefore, obtaining the necessary landslide risk assessment report for construction from the NBRO is a primary requirement (refer Sections from Section C 1.2 onward for more information and conditions applicable to lands with ground slope

1.2.2 Basic Requirements for a Safe Structure Houses built on slopes or in hilly areas if not properly located are vulnerable to not only landslides but also to high winds, flash floods, mudflow etc.

depending on the environment Therefore, Hazard Resilient houses shall be located essentially outside any land susceptible to landslides and sufficiently away from any unstable or vulnerable areas, so that they will not be collapsed or buried or severely damaged. Even then, unexpected ground movements or vibrations may possibly affect the house due to any instability in a neighboring area. The hazard resilient house should be able to resist; • minor ground movements without damage to the structure, • moderate ground movements without structural damage but with some non-structural damage. • larger movements without collapse, but with some structural damage and some nonstructural damage. Although a certain degree of damage is acceptable in the house due to an unexpected event, loss of life is unacceptable. Accordingly, the structure of the house must be designed to ensure that it has adequate strength, appropriate rigidity, and will remain as one integral unit, even while subjected to very large ground movements. Flexible structures are most appropriate for hilly areas as these can accommodate movements without apparent significant distress. Steel or timber structures are generally used as the main material in them. The type of structure recommended in this manual for the landslide prone areas is a reinforced concrete framed structure in-filled with brick walls and stiffened foundations as specified in Section B with additional recommendations presented herein.

Land Selection Important! The following areas are not suitable for locating a house and therefore shall be avoided; • Areas prohibited or restricted by law • Areas designated as unsafe • Areas with a history of landslides • Areas where landslides are imminent • Areas prone to landslide hazards The type of terrain and the landslide potential are two important factors governing the suitability of land for house building. a) Type of terrain The type of terrain, for convenience, is expressed here in measurable terms of ground slope. In general, the steeper the slope becomes, higher the tendency for instability. Slope instability problems often occur on terrain with slopes that are steeper than 10o-15o. However, slope angle is only one of the factors contributing to ground instability and it is practically not possible to suggest general threshold values up to which a slope is definitely stable and beyond which the slope is unstable. In this manual, for the purpose of assessment of landslide potential the type of terrain is identified under five broad categories of ground slope based on the observations of past landslides in Sri Lanka, as given below. Type I: Type II: Type III: approximately Type IV: Type V: Flat Land - slope angle less than 5o or ground slope less than 8% approximately Gentle Slopes - slope angle between 5o ~11o or ground slope between 8%~20% approximately Moderate Slopes - slope angle between 11o~17o (or ground slope between 20%~30% Moderate Slopes - slope angle between 17o~31o (or ground slope between 30%~60% approximately Steep Slopes - slope angle more than 31o or ground slope more than 60% approximately

According to the category of ground slope, certain restrictions and conditions are imposed on construction activities. Therefore, in selecting the land and in implementing subsequent processes of construction, it is necessary to adhere to these requirements, conditions or recommendation made with respect to the type of terrain (refer Table C-1). The location that is been selected for the house is recognized to be free from any landslide risks or free of any signs or features that are indicative of landslide threats or slope instability, the following is applicable; • For Types I & II (Ground slope60%) : Construction is restricted except for essential development activities which require NBRO approval. Therefore, in general, housing construction is not recommended in such lands.

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b) Landslide potential Suitability of a site in respect of landslide potential shall not be judged merely from the characteristics of the site itself in isolation, but of a broader area which encloses and influences the site. Select the site only after proper assessment of the land and its surrounding area to identify the level of risk from landslide hazards, if any. A site selected for a house shall be free of any features that are indicative of landslide threats or slope instability. Therefore, the land should be located sufficiently away from such potential risk areas and features such as steep slopes, cliffs, escarpments, rivers, perennial or ephemeral streams and mountain channels.

1.2.4 a) Areas Not Suitable for Construction of Building Areas prohibited or restricted by law The land chosen for building a house may fall within a safe zone permitted for human settlement and construction of residential buildings or it may fall within a zone that is demarcated as prohibited or restricted zone for such activities. Reader should, therefore, seek further advice of the local authority to ascertain whether the land use is restricted or not. b) Areas designated unsafe Avoid building in any areas designated or declared as unsafe. Such areas are shown in the Landslide Hazard Zonation Maps as zones where; • Landslides are most likely to occur, • Landslides are to be expected, • Modest level of landslide hazard exists In the areas where a modest level of landslide hazard exists, building construction may be permitted after the landslide clearance for construction obtained from NBRO and only when necessary engineering precautions are taken and the construction plans are technically vetted and certified by specialists. Even if a site falls within an area demarcated on the hazard map as safe zone for construction, it is still necessary to physically ascertain that the site is hazard free now and also in the future. This is important because the hazard zones have been mapped at a smaller scale and the conditions of ground stability can change considerably due to subsequent changes in land use and topography, new developments etc., that may have taken place after the mapping was done. The level of the risk involved viz., No Risk, Low Risk, Medium Risk or High Risk can be broadly identified by referring to landslide hazard zonation map of the area where available. Map. 10 shows the areas for which the landslide hazard zonation maps have been published for different scales (refer to www.nbro.gov.lk/web/index).

c) Areas with a history of landslides Avoid building on existing landslides, old or recent. The chances of reactivation or future occurrence of another landslide or slope instability in an area with a history of landslides are generally high. Therefore, it is important to know whether the land has a history of landslides which pose any future risks by studying ; • Information on reported past or potential landslide hazards obtained from the local authorities or from the NBRO. • Information that could be gathered from local residents who may be knowledgeable on any past events or any existing hazards in the vicinity. When any such information is lacking or not available, it is still possible and desirable to identify whether the land has a landslide history by studying the existence of abnormal landforms, unusual behavior of trees and structures etc., which may indicate past ground movement due to landslides. If there are any doubts about the safety of the site, professional advice and services shall be sought. An area with a history of landslides may have one or more of the following features which are indicative and helpful in identifying a past landslide; Landforms such as; • Old scarps existing on the slope; steep, curved scarps that are common at the top of landslides • Uneven hummocky ground with subsidence or heaves which often indicates a former landslide • Bulging ground appearing at the base of a slope •

Cracks on the ground surface Abnormalities in existing structures, vegetation etc.; • Trees that lean in different directions or having bent tree trunks (knees) • Tilted or leaning fences, walls or utility poles/posts; • Moved structures such as houses, retaining walls • Cracked, bulged, tilted or off-set retaining walls, stone hedges • Tilted and/or moved ancillary structures such as concrete steps, sidewalls, pavements, floors and patios gaping away from the main structure/ house • Patched or un-patched cracks in the walls or foundations.

d) Areas where landslides are likely to occur SECTION C Some features or tell-tale signs that might be noticed prior to an impending landslide due to reactivation of an old landslide or development of a new landslide or rock fall are given below. Knowing where landslides are imminent is important as the house occupants can take necessary measures for safety, even in a rare situation where the house happened to have been built on a land with risks undetected at the time of construction in spite of all surveys and studies. If any of the following signs are noticed within or in the vicinity, avoid building on such land and inform the local authority so that local residents could also be properly advised for necessary vigilance and preparedness measures. • Subsidence or heaving observed on the slopes, roads, pavements, ground, etc. • Sudden appearance and progressive widening or rapid expansion of cracks (refer Fig. C-2). • Bulging or heaving on ground surface, road pavements, or road beds • Ground water seeps to the surface in new locations; sudden appearance of springs, seepage traces or patches of ground saturation or water logging in areas that had normally not been wet before. • Sudden appearance and disappearance of creeks. • Increased turbidity in stream water flow. • Sudden oozing or appearance of water on the slope (refer Fig. C-3). • Continuous water logging due to poor slope drainage • Sudden movement of soil masses away from building foundations. • Tilting or leaning of trees, utility poles, fences, retaining walls, etc. (refer Fig. C-4). • Sudden breakage of water supply lines and other underground utilities. • Sudden appearance and rapid enlargement of cracks on walls, plaster, tiles, bricks or foundations of houses. • Tilting or cracking of concrete floors and foundations • Subsidence or bulging of retaining walls. • Exterior walls, walks walkways, or stairs begin pulling away from the building; • Doors and windows becoming out of plumb, sticking or jamming for the first time, • Unusual falling of leaves from trees.

e) Areas prone to landslide hazards Areas that seemingly appear to be stable and safe from landslides may sometimes have a potential risk. Avoid selecting a land at vulnerable locations such as; • Close to the base or top of a cliff or a cut or fill slope particularly where the slope is a steep • On or near steep natural slopes in weak geologic material with outcrops of fractured rocks • At or close to the top or along the nose of ridges adjacent to steep slope; • Close to the base of rock mass showing joints, outcrops of fractured rocks • On steep slope areas with thick soil masses free from vegetation; • On developed /cultivated hill slopes where irrigation or drainage systems are located. • On slopes close to where springs, seeping or ponding of water prevails • In relatively flat areas with thick soil mass and frequent seepage. • In areas where slope angle changes abruptly and variations occur in the thickness of soil overburden as a result of construction activities. • At the base of a steep slope with a lot of detached or buried boulders on unstable upper slopes • On Irrigated hillsides and steep slopes where surface runoff is directed onto the slope • On or near the path of mountain drainage • On denudated slopes where wildfires or human intervention have removed vegetation

Important! Areas prone to landslide hazards may also have some indicative signs similar to those where landslides have occurred or are imminent.

1.2.5 Layout Arrangement and Orientation of the House In planning the layout, orientation and shape of the house due consideration shall be given; • to minimize disturbances to existing slopes due to excavation and cutting required for land preparation and foundations, • to minimize the volume of earthworks and hence the cost of construction. Plan the layout and internal spaces as far as possible to fit into a simple structural system. On gentle slopes, the house may be planned to be built on a single, levelled formation in natural ground. If the ground slope is moderate, • The house may be planned as terraced house i.e. with stepped floor levels and built on two or more platforms at different levels cut into natural ground to match with the ground slope profile (refer Fig. C-5). By utilizing terraced housing or foundations to suit the ground slope, ground disturbances and earthworks can be significantly reduced. • As an alternative the house can be planned, with necessary professional advice taken, as an elevated structure on columns or raised footings supported on natural ground causing least disturbance to the slope (refer Fig. C-6). • A group of houses as in a housing scheme should be planned professionally considering the general guidelines that will be provided by the local authority.

a) Orientation of the House SECTION C Foundation Elevation To Suit Slope Fig. C-6: Foundations to Suit Slope Houses founded on a single platform should preferably be planned to have their longer sides running parallel to the natural contour lines. This can avoid encountering large differences in sub soil conditions and reduce cutting and filling work (refer Section C 1.5 on Foundations). b) Shape of the Structure Simple and symmetrical shapes such as square or rectangular shapes are preferable to minimize adverse effects from possible ground movements or ground disturbances. c) Land Space requirements The house shall be located at a sufficiently safe distance away from the toe of steep slopes, protected or unprotected natural or manmade slopes. The distance so required shall be decided on the advice of the engineer. For safe space to be kept between the house and toe of cut slopes refer Section C 1.4.2. Additional land space needed for the provision of access roads, garage and other facilities, such as for sewage disposal and the space required for cut and fill slopes, berms, retaining structures etc., shall be taken into due consideration at the planning stage. 1.3 Land Preparation Prepare the ground, in a single or multiple terraced formation on berms so that, it cascades parallel to the natural contours of the slope. Avoid deep cuts and/or high fills and the need for their protection with costly structures (refer Section C 1.4 Earthworks and 1.7 Earth Retaining Structures). Unless essential, do not remove vegetation and large trees which can provide stability and protection to the slopes. Limit clearing and stripping to the minimal area required for construction. However, where filling is required, all vegetative and other unsuitable matter such as loose/soft top soil, debris, shall be removed before placing any fill material.

1.4 Earthworks All earthworks involved with cut and fills for site preparation, access roads, excavation for foundations and trenches shall be designed and executed to ensure safety and stability during and after construction. 1.4.1 Cut Slopes The permitted slope angle of cut surfaces of temporary or permanent excavations depends on the soil type and several factors such as the height of cut and how the slope will be protected. Steeper slopes are permitted for cuts in competent bedrock. But in weathered rock slope depends on the weathering condition and the dipping of bedding planes (refer Fig. C-7), foliation planes or principal joint sets in rock formation. The cut slopes in different soil or rock formations up to a maximum height of cut of 3m, with or without a retaining wall can be utilized in accordance with Table C-2.

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1.4.2 Space between House and Cut Slopes Adequate safe space shall be provided between the house and the toe of the cut slope. The safe distance (d) between the house and the toe of cut slope depends on the height of cut and whether the cut slope is supported with a retaining wall (refer to Fig. C-8). • For free standing cut slopes, the distance (d) should be equal to the height (H) of the cut slope. H H Fig. C-8: Space between House and Cut Slope • If the slope is stabilized with a retaining wall, the distance (d) should be equal to the height of the retaining wall or house

1.5 Foundations SECTION C • The house, and hence its foundations, shall be located sufficiently away from unprotected slopes natural or manmade slopes (refer Fig. C-10 and Table C-1). • Where the building footprint crosses both cut and fill areas, footings shall be taken below fill and supported on a suitable bearing stratum in natural undisturbed ground. • The bottom of the footing shall be at least 1.0m below the existing ground level or the finished ground level whichever is lower, including on the cut/filled part. • The size and depth of foundation shall be decided depending on the type of subsoil and its bearing capacity (refer Table B-5 in Section B). • Footing on sloping ground should be constructed with sufficient edge distance, minimum 60cm to 90cm, for protection against erosion. • The difference in elevation between footings should not be so great which may cause undesirable overlapping of stress in soil.

1.6 Stabilization and Protection of Slopes All cut or fill slopes constructed shall be appropriately protected and stabilized against erosion, degradation and failure. Slopes that are cut or filled to a safe slope angle may be protected and stabilized e.g. with vegetation or a blanket of natural grass which is economical and aesthetic for landscaping. Unstable cut, fill or natural slopes shall be stabilized either with an externally or internally stabilized system. Externally stabilized system consists of a structural wall to take up the pressures exerted by the soil and water that is retained behind the wall. Internally stabilized system involves strengthening or reinforcing the earth mass of the slope. There are numerous methods and materials used for slope stabilization and protection

1.7 Earth Retaining Structures When soil is to be retained in near vertical deep profiles or steeper profiles, soil may not be stable on its own and it would be necessary to provide additional support from a retaining wall of appropriate type. The types of retaining walls widely in use are; gravity walls, reinforced concrete walls and embedded walls.

1.7.1 Gravity Retaining Walls Traditionally, these walls are constructed with mass concrete or random rubble masonry with mortar or with interlocking pieces of rock without the use of mortar (dry rubble masonry walls). More recent forms such as gabion walls and crib walls also fall into this category. Gabion walls are made by assembling boxes packed well with rubble to form the desired height and width. Boxes are made with hexagonally woven galvanized wires. Wires are provided with a pvc coating in some instances to enhance the resistance to corrosion. Boxes are available in different sizes and tied along the edges to form the wall of desired dimensions. As there are large void in packed rubble, gabion walls are highly permeable. Gravity walls depend on their own weight for stability. Possible sliding or overturning due to the pressure exerted by the retained soil is resisted by the self-weight of the wall. When the height to be supported increases, the required weight of the wall increases significantly.

Walls made with random rubble masonry or mass concrete are not permeable and drainage of any water accumulated behind the wall should be a facilitated by providing weep holes at appropriate horizontal and vertical intervals. In the permeable walls such as dry rubble masonry walls or gabion walls weep holes are not necessary, but a filter layer (granular or geotextile) should be provided behind the wall to prevent movement of retained soil into the void spaces in the wall.

1.7.2 Reinforced Concrete Walls

Walls made of reinforced concrete in the shapes of “L” or “Inverted T” can also be used to retain soils. The weight of the soil lying above the base is added to the weight of the wall to maintain stability. Therefore the wall should be of sufficient base width. The wall stem should be adequately reinforced to withstand the bending moment exerted by the retained soil. Walls can be in the cantilevered form or laterally stiffened by counterforts or buttresses. This lateral stiffening will reduce the bending moments on the wall stem. The resistance to sliding can be enhanced by providing a shear key.

1.7.3 Embedded Walls Walls embedded to an adequate depth can be used to retain soil. This type is particularly useful for supporting excavations. Embedded wall sections can be of preformed from; timber, steel or masonry and driven to the ground to an adequate depth before excavation commences. However, walls made of steel (steel sheet piles) are the most widely used type. Alternatively, a wall of necessary depth can be constructed with insitu concrete in the form a diaphragm wall or by a continuation of a line of bored piles. Diaphragm walls are constructed in the form of interlocking panels. Bored pile walls can be constructed; with an overlap (secant pile wall), touching each other (contiguous wall) or with a gap between piles (intermittent walls). If an excavation is extended below the ground water table, use of a secant pile wall is recommended. Embedded walls can be done in the form of cantilevered walls or laterally supported at one or more levels by anchors or props. With the usage of lateral supports, the required depth of embedment is reduced. Lateral supports will reduce the deformations as well. The stability of an embedded retaining wall is derived from its depth of embedding and lateral support. The wall section should be of adequate structural stiffness to withstand the bending moments developed.

1.7.4 Drainage behind Retaining Walls Due to rainfall or other wet conditions, the backfill of a retaining wall may become saturated. Saturation will, in effect increase the pressure on the wall and creates an unstable condition. For this reason, adequate drainage must be provided by means of weep holes and/or perforated drainage pipes. Minimum diameter of a weep hole is about 100mm and they should be placed sufficiently close (1.5m to 2.0m horizontally and vertically) Note that there is always a possibility that the backfill material may be washed into weep holes or drainage pipes. This will ultimately clog up the drainage facilities and may cause the earth fill on top to subside. Thus, a filter material should be placed behind the weep holes or around the drainage pipes. Filters may be constructed from graded aggregate or with a geotextile.

1.8 Soil Erosion Control and Drainage Most of the landslides in Sri Lanka have occurred when heavy storms and prolonged rainfall have been experienced. Rains, while contributing to surface erosion of the soil on a slope, also percolate into the soil filling the voids. This reduces the matric sadiron of the soil and saturates it, making it more heavy in turn. The groundwater level can also rise. There will be a reduction in the strength of soil. Even a slope that appears to be stable under dry conditions may become unstable due to poor drainage of the slope. Therefore, it is extremely important to manage both surface and subsurface drainage of a slope. The areas that should be avoided when building on slopes and the areas that may be considered as suitable for housing construction are recommended in Section C 1.2.3 of this manual. Even if the land is carefully selected, all precautions shall be taken to ensure that soil erosion is controlled and the surface and subsurface drainage is properly managed in order to sustain the stability not only of the premises of the house but also of the surrounding lands.

1.8.1 Soil Erosion Control Soil erosion can happen as a result of rain splashing against the soil surface, flow of surface runoff and formation of gullies. Erosion of banks and bottom of gullies and streams occur due to rapid water flow. These conditions can eventually contribute to slope instability. This manual recommends the builder to ensure minimizing soil erosion by adopting the following methods; • Minimize disturbance to existing terrain as far as possible by matching development to the terrain and limiting adjustments to existing ground contours. • Minimize exposure to soil erosion by planning the construction and scheduling so that the extent of exposed areas and the duration of the exposure are minimized and the grading works can be done during relatively dry seasons. • Minimize clearing of site by retaining existing vegetation as vegetation helps reduce run off velocities and volumes. Use plants like Vetiver grass (savandara variety) for re-vegetating (refer Appendix A). • Optimize slope angle and length. • Divert runoff away from cleared areas and minimize runoff velocities by grass lining of diversion trenches, use of broad and shallow flow areas, network of surface drains and rock fragments on slopes. 1.8.2 Surface Drainage It must be ensured that natural drainage, stability and environment of the land and surrounding area is not adversely affected during and after construction. All water from rain, springs and waste water shall not be released on or in to the slope and shall be properly directed away from the slope appropriately into natural water courses or the local storm water drainage system or the wastewater drainage systems as applicable.

Following measures are recommended; SECTION C • Provide interceptor drains to collect and divert runoff and springs to prevent surface flow within any unstable or cleared area. • Provide diversion drains to prevent water flowing into any unstable or cleared area across its periphery. • Provide silt traps / silt fence to prevent blockage of drains due to siltation. • Line the trenches and channels to minimize erosion. • Utilize flexible material or flexible joints if pipes are used to drain water. • Provide structures to dissipate energy and reduce the flow velocities in channels. • Provide adequate reservation for existing natural streams or drains. • Provide culverts, concrete pipes etc., as required for access or internal road crossings. • Provide adequate flow capacity and slope and drops in all drains, channels, pipes etc., to prevent blockage. 1.8.3 Sub-surface Drainage Rise in ground water table within the land due to rains or any other reasons can result in instability particularly of any cut slopes or generally unpleasant environment with sodden ground around the house. It is, therefore, necessary to control groundwater table and/or seepage flows. Following measures are recommended; • Intercept the groundwater and properly divert it away from the land using a French drain or sub surface drains. French drain consists of a perforated hollow pipe wrapped around with a filter of geotextile fibre and surrounded by permeable material such as sand and gravel packed within a lateral trench. The pipe should have a proper gradient and an outlet to a suitable surface drain for the intercepted water to flow away swiftly. These drains are more suited when the groundwater rises to within about1.5m from ground surface as deeper excavation could be costly. • Provide sub-surface drains in to help lower the ground water table and prevent build-up of hydrostatic pressure against the walls. Ensure that; • Adequate number and area of weep holes are provided. • pipelines used for construction of all subsurface and diversion drains are of flexible materials and with flexible joints provided to accommodate ground movements and to prevent breakage and leakage • manholes are provided at appropriate locations for maintenance. • Surface runoff is diverted separately preventing inflow of surface water in to sub-surface drains.