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Visual Inspection Of Structures - Primary Aspect Of Structural Health Assessment

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Abstract: This article focuses on importance of visual inspection to observe conditions that can lead to structural and non-structural failures in civil construction. The subject article is based on structural failure reports information, condition assessment in generalized manner and practices which are being accepted in normal practices. Visual inspection procedures may help to identify the structural deficiencies in particular structural elements prior to becoming critical to challenge overall stability of integrated structure. Only generalized dangers can be revealed in visual inspections of the deterioration of structures. Experienced structural engineer is required for complete analysis of major structural defects.

Keywords: Structural health, Visual Observation, Site inspection, Structural Deficiencies, Construction practices, Cracks, Non-destructive tests.

1. Introduction

Structure can be visually inspected at fixed frequency, after disasters like flood, fire and earthquake and even immediately after construction. If periodically structure can be inspected for sign of distress, then not only performance can be judged on basis of historical records but also durability of structure can be strengthened by timely detection of damages or distresses. Visual inspection provides further planning the structure is subject to, either repair, retrofitting, rehabilitation or to demolish [1-3]. During the process, proper documentation, proper observation based on environmental conditions and load criteria is needed. Non-destructive test, destructive test and other related tests are required based on the observation of visual inspection if required to access internal conditions of structure [4-5].

Inspectors and facility engineers are provided with observations of visual inspections so that systematic methodology can be developed for further course of actions to avoid further deterioration of structure. Repair techniques are not prescribed in subject article also structural defects are also not being addressed. The subject article intends to provide inspectors the technical and geographical information aid in evaluation the deterioration conditions of structures visually [6]. It is primarily for evaluating general civil structures, like buildings, retaining walls, transmission line towers, bridges, culverts, overhead water tanks, etc. but not for mass concrete structures [7].

1.1 Visual Inspection As A Part Of Structural Health Assessment

Going by an old proverb which says: “A Stitch in Time Saves Nine”, visual inspection is the most important part of health assessment of any structure as schematically shown in Fig. 1. Structural health assessment detects damages and places the structures into three categories.

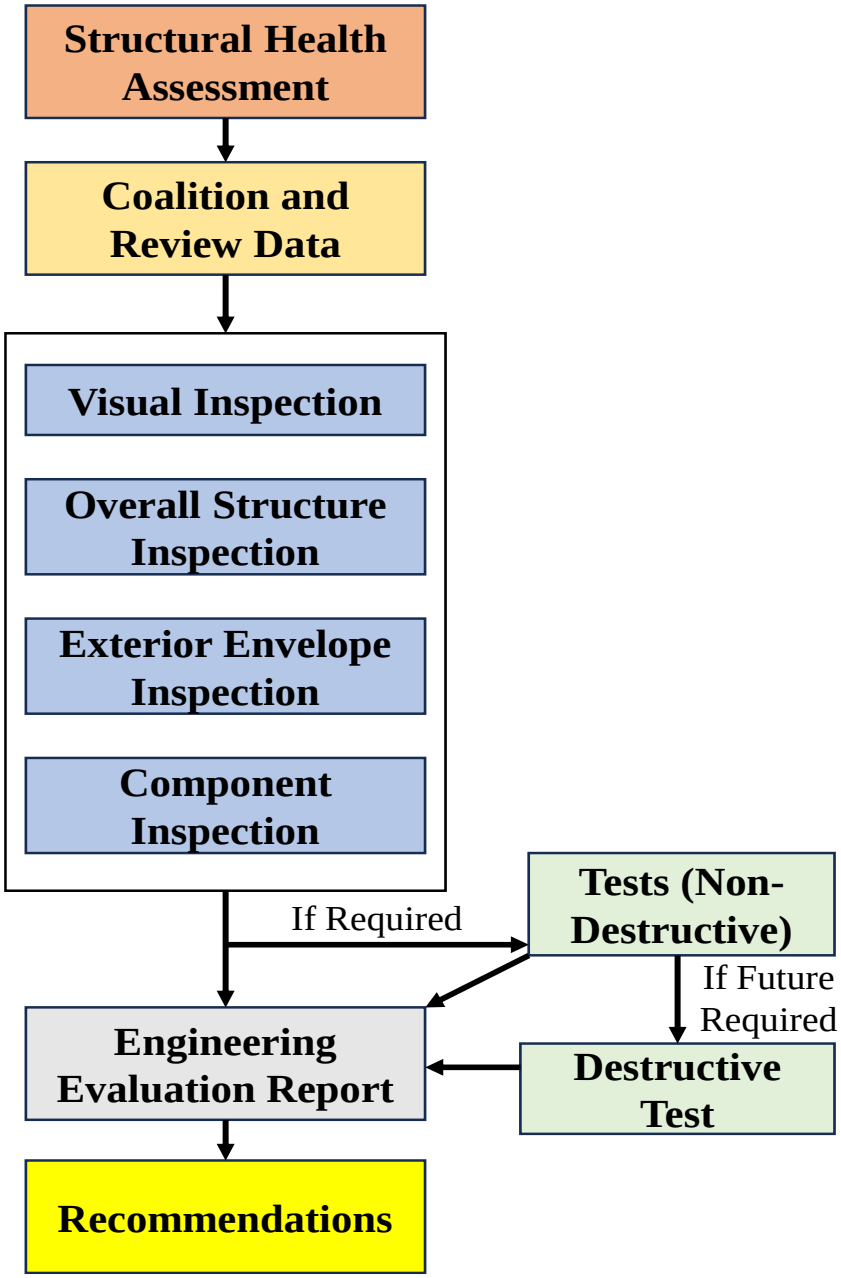

Fig. 1: Structural Health Assessment

A. Signs of distress are not found in structure and safety and service conditions are complying relevant IS codes. Repair, retrofitting, and rehabilitation are not needed.

B. Deficiency is found in structure however same can be strengthened and repaired so that IS code compliance may be done and structure can be retained with structural strengthening.

C. Structure if found damaged badly. Either to be demolished or if required new construction may be done.

After visual inspection of any structure it is decided if to carry retrofitting / rehabilitation for structural repair or to demolish the damaged building if the condition is beyond structural repair [8]. The factors considered are stability, durability and cost-effectiveness. The Assessment Process in totality consists of Collation and Review of Data, Visual Inspection, Non-Destructive Testing, Testing Works, Engineering Evaluation Report and Recommendation.

1.2 Need For Periodical Visual Inspection Of Structures

Any structure is required to be inspected visually at certain time interval or as per requirement to find structural and nonstructural deficiencies, for immediate strengthening of any structure, to decide further changes like use of structure or rehabilitation / retrofitting, to examine the condition of structures after suffering natural and / or manmade disasters like earthquake, cyclones, tsunami, flood, landslides, explosions, fire, overloading, construction / design deficiencies, etc. Visual Inspection may even be carried out immediately upon completion of construction of structure before / during or after taking over the asset [9-11]. Visual inspection is also recommended for any structure to ensure its compliance to statutory requirements as also to relevant latest IS codes , to know the causes and extent of defects, to determine present and future safety, cost of repair if proposed, future maintenance plan, load limitations and residual life, it aims for overall appreciation of structural condition, identify nature and types of problems, map out the extent of the problems, identify types of defects, possible causes, follow-up investigation / testing, to determine if problem is structural in nature or material deficiencies are there, confirms present safety level of structure, diagnose persistent defects of aging structure [12]. If on visual inspection structure is found to be good enough to be declared safe for future use, then no tests are required and if structure is found to be extremely dilapidated then also no further tests are required to recommend decision of demolition [13].

Visual inspection is first step and forms the basis for all further tests and decisions to be taken in health assessment of structures. Even for ascertaining the exact locations or points for non - destructive tests to happen, visual inspection needs to be carried out carefully [14].

1.3 Requirements For Visual Inspection

To carry out Visual inspection of any structure one requires knowledge and experience, accessibility to structure, health and safety considerations. The essential equipment needed are – the human intellectuality , aided with record book, pro forma, geo tagged camera (with date, place and time mentioned on photographs), computer measuring tape and binoculars, rule, inspection mirror with swivel head calipers, plumb bob, straight edge feeler gauges, binoculars, camera and film, screwdriver, heavy duty pliers, flashlight, clipboard and marker or chalk, pocket knife for chiseling, magnifying glass, crack comparator level, wire brush for cleaning the surface, ladders or other special equipment to reach difficult areas are also required. Safety measures not to ignore in while inspecting the structure visually [15-16]. Normally time, date and weather conditions to be recorded while surveying. All the defects need to be photographed [17].

To not miss every single point while inspecting it is better to prepare a checklist for each type of structure mentioning the defects and putting it in category general, medium and high [18]. The recommendations for further test required, if any, repair for the findings and declaration of structure being safe or not safe are to be mentioned at the end of the checklist itself.

The steps for visual inspection of structures are covered in three steps - Site inspection, Exterior Envelope Inspection and Component Inspection - which covers the presence of cracks, corrosion of steel bars spalling of concrete, damped area, rust staining sign and water runoff places, distortions, deflections, the categorization of all the findings into structural and non-structural deficiencies, further potential places of threat and damages are extracted and further results and its interpretation confirmed by testing if required [19-20]. The visual inspection detail is shown in Fig. 2.

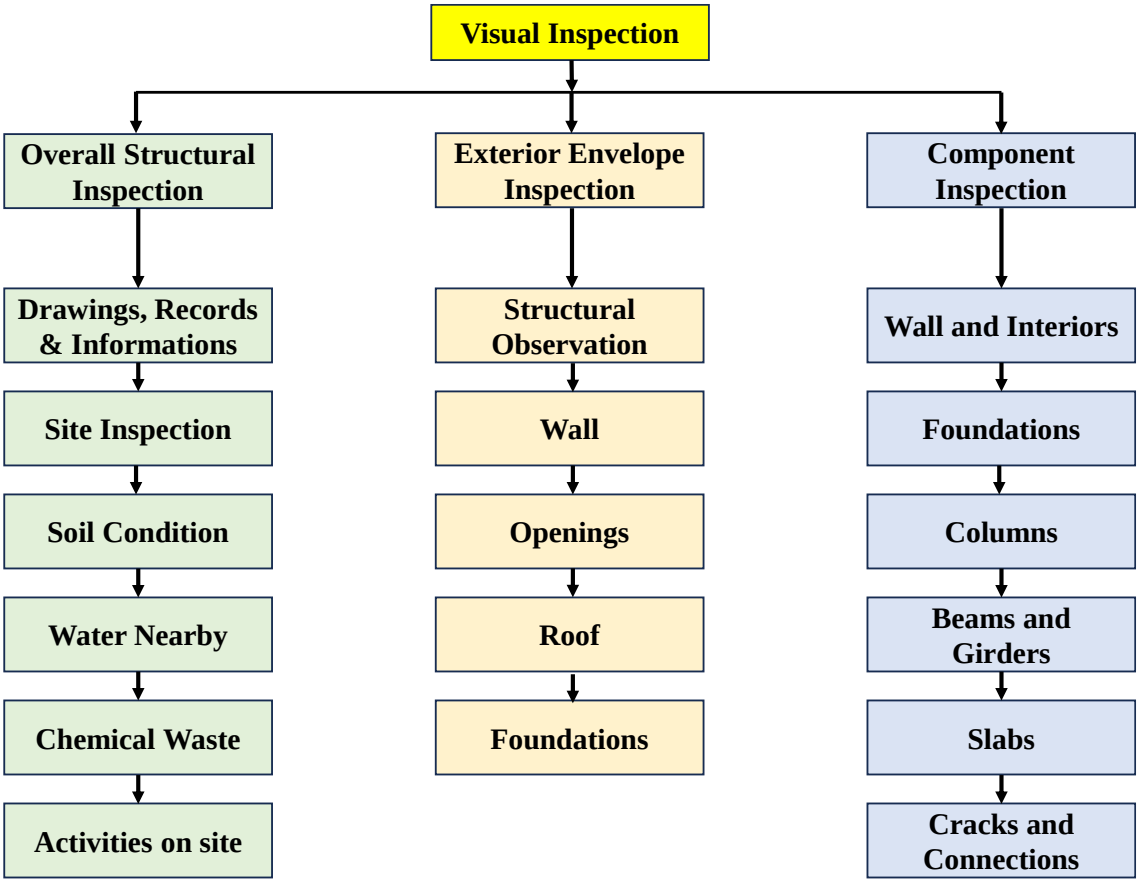

Fig 2: Visual Inspection Detail

2 Overall Structure Inspection

2.1 Drawings, Records and Information

Study is needed prior to observe the structure visually for construction documents like Standard field quality plan, construction drawings, changes in usage of structure, change in structure after construction, Material testing reports, As-built drawings for structural, architectural, water supply, electrical, construction specifications with addenda, soils test reports, pertinent correspondence, performance related document, records of repair and maintenance, and Prior inspection reports (if available). The seismic activity, flood, tsunami, wind and other geographical and geological detail related to structure are to be accumulated. Any past distress like earthquake, fire, flood, repair, renovations, change of use of structure, change of water table, settlement, snow load damage, wind damage, vegetation damage etc. that the structure may have suffered also needs to be studied [21]. Apart from that name, address, number of storeys / height of structure, description of main usage and maintenance history of the structure are also to be recorded. The quality of construction materials used is to be noticed.

Sketches of the structural frame and floor plan of structures is to be prepared with help of 'as – built' drawings. But actual spans of girders, beams, and slabs are to be measured, dimensions are to be recorded on sketch and cross verified with the 'as built' drawings. Verification of accuracy of original drawings can be done with existing structure. Determination of basic building information is needed if original drawings are not available. Each floor of building sketch to be prepared as shown in Fig. 3. The convention of numbers and letters along horizontal axis and vertical axis (left to right) and (top to bottom) respectively must be developed as standard practice. Specific beam, column, or bay where a problem is identified must be designated with letter number combination. If any problem will be traced then the location is to be mentioned in Inspection Checklist.

Inspection Checklist is to be prepared considering all the factors like overall structure inspection, exterior envelope, component inspection of particular nature of structure as shown in Table 1. The damages are to be categorised as mild, medium and severe.

Table 1: Sample of Inspection Checklist

NAME AND ADDRESS OF STRUCTURE					
DETAILS OF SPECIAL FEATURES					
SEISMIC / FLOOD / CYCLONE / LAND ZONE DETAIL					
PLAN AND ELEVATION DETAIL (AREA, DRAWINGS etc.)					
HISTORY AND USE DETAIL					
PREVIOUS DAMAGES AND MAINTENANCE DETAIL					
SL. NO.	**DESCRIPTION**	**DETAIL**	**MILD**	**MEDIUM**	**SEVERE**
1	**OVERALL STRUCTURAL INSPECTION SECTION**				
A					
B					
2	**EXTERIOR ENVELOPE SECTION**				
A					
B					
3	**COMPONENT INSPECTION SECTION**				
A					
B					

2.2 Site Inspection

Site environment, characteristics of soil, drainage of water or sewage, stagnancy of water or sewage, proximity to chemical waste body or water body, site activities are to be noted. Corrosive elements in the soil from buried chemicals and effects on structure must be noted. One has to study nearby structures, their height, uses and age.

2.3 Soil Movement

Foundation structure can suffer severe damages due to Soil movement under slabs, foundation walls and piers etc. Sil movement on being transferred to superstructure can cause shear force and torsional effects which in extreme cases can overturn the structure. Load bearing soil strata failure, consolidation of soil, moisture content variation of soli, compaction of soil, instable slope, earthquakes and heave due to frost, soil shrinkage due to heating, soil swelling due to freezing, mineral extraction (tunneling), soil compaction due to vibration, settlement due to collapse of cavities, movement due to construction on or near the site, erosion of subsurface, swelling in clayey soil due to moisture, water supply and faulty drains caused soil erosion. Basement wall, retaining wall, etc. leaning and cracking etc. are to be observed. Animal burrow causes exposure of foundations. Differential settlement due to contraction and expansion of Black cotton soil is to be noticed whereas, on the other hand, differential settlement also needs to be examined on structures above murrum soil which is relatively better for construction. If soil is cohesion-less and granular in nature, then must be observed for liquefaction and differential settlement effects.

2.4 Water Presence

Water must not be stagnant near to any structure's foundation. Horizontal pressure increases for water saturated soil in contact with the foundation wall. Penetration of moisture causes freeze/thaw deterioration. Growth of algae and fungi on concrete must be noticed. Ponding part where soil meets wall in ground, should be checked. Active water body if passes near to any structure can cause erosion which may later cause collapses. The horizontal distance of structures from water source is to be noted. The locations of septic tank, soak pit and bore are to be noticed.

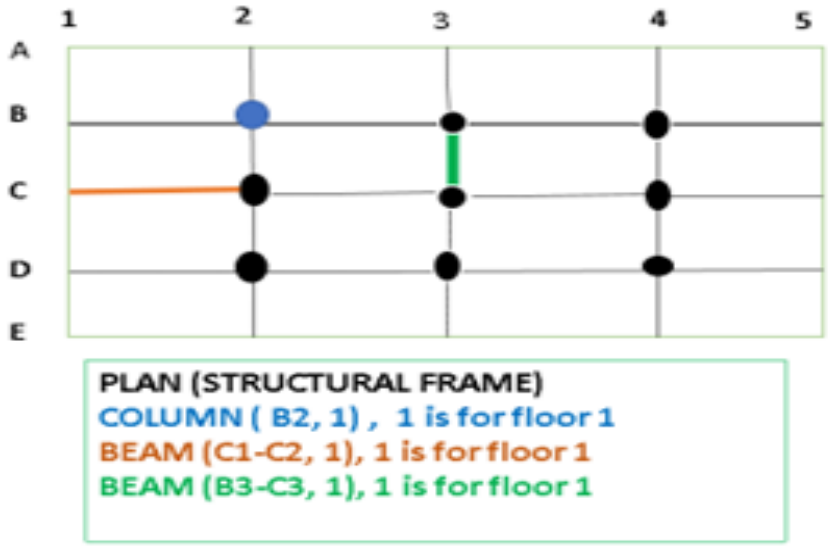

Fig 3: Structural Plan

2.5 Chemical Waste

Leakages of chemical wastes from storage tanks, factories nearby or dumped site can cause corrosion of reinforcing steel and weakening of the structure significantly. The area nearby is to be checked for this.

2.6 Site Activities

Deterioration of the concrete structure can be due to site activities like passing vehicles like train trucks can cause vibrations which in due course of time may leads to cracks if on designing the factors not considered. Even factories and industries nearby are to be noticed as these are regular modes of vibration. Large equipment foundations also can cause vibrations and cracks may be generated hence site activities to be noticed.

3. Exterior Envelope Inspection

Inspecting the factors exposed to outside environment of any structure walls, windows, doors and roofs, columns, etc. fall in Exterior Envelope Inspection. This section helps to study the causes of damages and deterioration due to changing environment cycle exposure.

3.1 Structural observations

The shape of structures plan wise and elevation wise, irregular mass distribution are to be noticed. Even if length of structure is more than three times its width, then possibilities of cracks will be there. The ratio of length to width of the structure is to be taken care at the time of visual inspection. The bents in plan of any structures may be points of cracks or seismic weakness; these are to be inspected as well. In multistoried units it is to be observed that the width of lower floor is at least that of storey above. If width of upper storey is more than that of the lower storey it is to be noted and examined for any defects as it is the point for irregular mass distribution and hence defects. All the buildings with open ground storey with absence of RC structural walls for support apart from columns are to be inspected properly, especially the columns. Termite effects on structure are to be noted.

3.2 Wall

External walls suffer the thermal expansion, contraction, differential settlement most. The defects like cracks, scaling, abrasion and other may be transferred to the interior. Coverings like paneling or veneering to be removed for a certain suspected part or portion decided as per intelligence to capture maximum load effects. The defects to be noted on exterior walls are deflections, cracks (if only surface crack or deeply penetrated cracks), defects due to temperature, chemicals, weathering, blistering, scaling. The type of wall is to be noticed if load bearing or RCC or mix of both. The deficiency or damages like deflection of beam can crush wall below it hence deficiency

or damages on the exterior wall can be indicative of a structural deficiency of nearby structures. The exterior wall is to be examined for deformations like cracks, angular displacements from the vertical orientation and deflection. walls may be indicative of structural damages may be reflecting crack pattern and bowing. Out of plumb wall, bulging and unevenness on wall surface, sign of water infiltration, sagging around opening, diagonal cracks at the corner of openings of wall, reinforcement, extent of corrosion are to be noticed. Damage due to vegetation growth (cracks due to *peepal* and *banyan* tree penetration on walls) is to be inspected.

3.3 Openings

The size and location of window openings are to be noticed, since large openings are not very favourable to structures. If the openings are near to corners then it is also to be noted. Windows and door frames separation from wall surface to be noted in buildings. For RCC, framed openings are part of wall load. Distortions like sagging, buckling or bowings of window grills and door frames due to load and forces of wall or slabs to be noticed at lintel, sill and thresholds that should have normally passed to the ground. Distortion sizes has to be recorded. Diagonal cracks at the corners of openings occur either due to percolation of water into the reinforcement steel or due to improper diagonal reinforcement in the structure, is to be noticed. Windows and doors are also subject to abrasion and impact from whatever passes through them. Windows and doors are to be recorded for edge damage and impact sign. Distortion of openings, window frames, grills from original status, their percentage wise deviation to be noticed. Even if the structure is having too much openings, these are also to be noted.

3.4 Roof

Roof to be noticed for any cracks, depressions, water proofing, ponding and other defects. Imposed load increased due to ponding, the same designing factors may not be considered while designing. Clogged drains, evidence of water infiltration at opening and sag at roof surface to be examined. If the building is old and water is getting logged on roof that may increase the live load or imposed load which finally leads to collapses. This generally occurs in rainy season. Damage due to vegetation like seeds of trees penetrating the roof surface and cracks if any is to be noticed. Roof treatment has been done or not, is to be noticed. If roof is capture area, it needs to be noted if it is for rain water harvesting.

3.5 Foundation

While visually examining the foundation cracks near downspouts, structures's corners and near column supports of foundation wall or piers, is to searched out for. The cracks may be due to differential settlements of soil or due to liquefaction effect. Type of foundation is to be taken to notice. The condition of plinth protection and their covering with soil must be checked. Damage due to vegetation like root penetrating to foundation may be inspected.

3.6 Others

Cracks, deflections, corrosion, spalling and distortions on outer columns, beams, walls and on any steel structures are to be noticed which are on exterior part, its pattern to be sketched, if active or passive in nature, the part where it is occurring, on columns, beams, walls, foundations, the building / structure need to be noticed, if equipped with earthing or not.

4. Conclusions

1. Structural health assessment assumes a crucial part in any structure's journey.
2. During useful service life of structure maintenance activity can continues. Regular planned maintenance and upkeep of the structures shall certainly enhance the useful life and curtail the decay of the structures in post construction part. Visual inspection**,** thus**,** plays a crucial role.
3. The structures shall always comply with the relevant standard Civil Engineering codes in considerations for safety purpose as well as for useful safe life of the structure.
4. The periodicity of visual inspection should be on half-yearly or at the maximum on annual basis. Visual inspection, additionally, has to be performed after being exposed to distress like flood, earthquake, fire, cyclone, tsunami, lightning strike, land slide, cloud burst etc. as also immediately after completion of any new or additional construction work getting over on any structure.

5. As per the structure's detail a checklist is to be prepared for visual inspection, covering all the structural and architectural observations.
6. Unless there are any telltale signs of structural damages or defects, the visual observation through proper checklist is sufficient enough. If the structure is suspected to be damaged then also, primarily, visual inspection shall be required before recommending to declare it as dilapidated and fit for demolition.
7. If no structural deterioration or defects found in any structures, the visual observation is considered sufficient for any further planned action. If, apparently, upon visual assessment signs of significant structural deterioration or defects are present, the professional assessment of the deterioration or defect and recommended appropriate actions are required to be taken. Such actions may involve either repair, reconditioning works or full structural investigation of the affected parts or entire structure for recommending any suitable action.
8. It is sometimes not possible to inspect 100% of all the areas in a structure within a reasonable period of time owing to difficulties of access and other practical problems. The dangers of prescribing any percentage lower than 100% is the possibility of doing the minimum, with the possible consequence of missing something important. It is, therefore, generally recommended that the visual inspection of all accessible units or areas of the structure have to be performed. This is especially so for structure where the imposed loading is high or unpredictable, usage varied or likely to be subjected to abuse or overloading especially in cases such as factories, industrial buildings, warehouses, shop houses, public assembly areas, culverts, retaining walls, mixed use foundations and columns under dynamic loading, check dams, water retaining structures, etc.
9. The covered or veneered surfaces may require part or full removal as per the, utility, condition and location of structure so as to have full exposure for visual inspection.
10. Structures where the imposed loading is light, usage is fairly uniform and overloading ins unlikely event (such as residential apartments, hotel rooms, general office areas etc.), or if a reduced percentage of coverage is inevitable, the inspection sampling must be evenly distributed throughout the structure. If there is any possibility of abuse or overloading and signs of significant structural defects and possible deterioration of any structure, 100% inspection of the structure has to be considered.
11. Special and critical structural elements or with no redundancy like (e.g. transfer girders, slender columns, cantilever structures, long span structures, cable structures, connections and support conditions, etc.) must be inspected thoroughly for all parts.
12. Limitations: Covering of main structural elements by architectural finishes may require exercising professional judgment to expose particular parts as per structural layout plan. Accessibility of each and every part to inspect may be not possible. However, it is recommended that during planning and construction stage adequate provisions be considered and enabled so as to facilitate periodic inspection.
13. Repairs arising after visual inspection: Major structural repairs and strengthening work must be planned after further corroboration by proper non-destructive test, destructive tests and proper design and drawing analysis. Routine maintenance may include minor repair recommended.
14. Visual inspection report must be signed and endorsed by the inspector appointed to carry out the inspection and supported with photographs, recommendations and test reports if required. The inspector shall submit the standard certification form as considered appropriate depending on visual inspection detail.

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