Vulnerability Analysis: A Critical Tool in Asset Management

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Abstract: Engineering works in respect of the built environment were developed generally after the execution of a feasibility study. If the conclusions were favourable, the facilities were constructed, and they were generally expected to last their design life. Maintenance was considered only when the facility began to manifest wear and tear or deterioration. Maintenance of physical assets was considered an inevitable but necessary after-thought. In order for the asset to provide maximum usefulness throughout the design life, maintenance must be contemplated and planned for at the point of the design phase. Design consultants are being required to develop maintenance manuals to be provided to the client at the commissioning of the facility. On the continuum of the feasibility study, recent additions have been the Environmental Impact Assessment, and more specifically, a Vulnerability Assessment that completes the full study of any proposed facility. The assessment has become 1) the litmus test that any study must satisfy and 2) the critical tool in extending the useful life of any built facility. This paper discusses how this phase of the feasibility study must be executed. It describes why vulnerability assessment has assumed such importance in asset management.

Keywords: vulnerability assessment, asset management, maintenance

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Introduction

Architects and design engineers when designing structures and facilities, contemplate that what they design will enjoy a useful period in service. This is what is commonly referred to as the design life of the facility or structure. They do not assume an eternity in use and seldom do they expect that the structure would last as long as the pyramid of Cheops, the Sphinx or the Parthenon. Most facilities are ascribed a less ambitious in-service life span. Most facilities that are put in active and continuous use will experience degradation and must therefore undergo periodic repairs. This will be minor in most cases initially and become extensive and significant towards the end of the service life of the facility. This may involve rehabilitation and renovation, especially when there is anticipated change of use of the facility.

In the case of historical buildings, when it is the intention to preserve the structure or literally give it a new lease on life, major works may have to be undertaken by way of retrofitting. The structure may be provided with an endoskeleton for support where the structure is no longer able to support itself or the new imposed loads. Buildings that have had their structural integrity seriously compromised by natural disasters often fall within this category. In some cases, this retrofitting is done to ensure that the structure is not destroyed by subsequent assault by natural disasters where the present body of knowledge can significantly better treat with these external imposed forces that were initially employed in their design and construction.

What was discussed so far has not included basic maintenance, the simple cleaning of the component parts, the reapplication of paints and coatings, replacement of lubricants, the replacement and/or tightening of fasteners, cleaning of rust, removal of fungi, restoration of protective layers that may have been ruptured by abrasive impact, chemical attack by the atmosphere, insect borings and the more recent concern of acid rain. Above all, maintenance is to deal with wear and tear from use and the normal ageing process. These are all central to the issue of facility preservation and asset management. To put this nevertheless in perspective, we must consider the project cycle of any facility or structure. More specifically, we must begin with the conceptualisation or feasibility study.

The Project Cycle and Feasibility Study

Prior to the decade of the 1980s, feasibility studies were conducted in three phases. The first phase was the Technical Feasibility in which we considered the availability of the technology contemplated or the engineering feasibility. This answered the question whether the project could be designed and built. This was critical and continues to be seen as such. The second phase was the Economic Feasibility which addressed the issue of cost benefit analysis in which we considered the cost associated with the projects versus the benefits that would accrue. The project would be considered unfeasible should the costs exceed the benefits. The next phase, the Financial Feasibility, addressed the issue of financing. Was financing available for the project? Here the evaluation is usually carried out using several financial tools, return on investment (ROI), net present value (NPV) and internal rate of return (IRR).

Prior to the 1980s, success in terms of these three phases of evaluation meant that the project would have been accorded the go-ahead decision. With the decade of the 1980s with growing concern about the environment and the advent of the concept, sustainable development, we saw the introduction of a fourth phase of project evaluation. This was the Environmental Impact Assessment (EIA). The EIA became the new litmus test replacing the financial feasibility and which soon all projects had to pass. Nowadays, the international lending agencies all demand that EIAs are undertaken for any project for which they provide funding. In fact, the local funding agencies have moved in step to require that projects have the necessary approval in respect of a satisfactory EIA. This would mean that no public sector project would be undertaken without a satisfactory EIA. For instance, private sector projects must also obtain a Certificate of Clearance issued by the Environmental Management Authority as stated in the Environmental Act in Trinidad and Tobago.

It is at this point that the idea of vulnerability analysis has to be introduced. The vulnerability of the project has in fact emerged as the critical test which all proposed projects must survive. This is not to diminish the value or importance of the technical/engineering feasibility or the economic or financial feasibility. Initially, this was aimed at large-scale industrial projects, infrastructure works or reclamation with the potential of pollution. Today, it applies to all major development works even involving housing, commercial estates, post-expansion or urban development projects.

Figure 1 shows the conceptual phase of projects. Structural or facilities projects must first be conceived i.e. pre-feasibility studies (highly preliminary). These represent at best approximate analysis to explore if the project should be pursued. The next aspect of this conceptual phase is the actual feasibility study, a more detailed analysis and the final phase, that of the design. Once the site location has been selected and the technical feasibility has been completed, the other four aspects may be initiated in parallel. In respect of the project life cycle, this must be added the construction phase. Finally, the in-service phase ends in demolition or retrofitting in the case of preservation of historic buildings and structures (see Figure 2).

(Insert Figures 1and 2 about here)

Figure 1. Conceptual phase of projects

Figure 2. Post-conceptual phase of the project life cycle

Vulnerability Analysis

The question of vulnerability analysis of built facilities or structures is of particular importance for designers, constructors and clients/owners in the Caribbean since the Caribbean region is under constant assault by a wide range of natural hazards. The region is visited each year from June to December by a number of hurricanes and tropical storms. These are accompanied by flooding in low-lying areas and are often ravaged in several coastal areas by storm surges. Slope instability is observed in several islands triggered by heavy rains. This results in landslides in hilly areas and embankment failures along roadways. The phenomena are observed in the islands where sedimentary rocks are one of the dominant geologic formations, as well as in volcanic-formed islands where hillsides are covered with unstable soils.

The region, again because of its geology, experiences continuous seismic tremors/ earthquakes with a history of significant shaking occasioning serious damage in several islands for all of their recorded history. The same geologic structure that is associated with these tremors, the relative movement of the geologic plates, is also connected to the history of volcanic eruptions experienced in the region. In fact, the Archipelagic Caribbean is described by and large as being the peaks of marine volcanoes along the interaction of the Caribbean and American geologic plates. Several islands have experienced volcanic eruption over the last century. Seismic tremors have also been associated with landsliding in the region. This lethal combination of phenomena (landslides, earthquakes and volcanoes) is described as the geological based natural hazards experienced in the region.

This paper is not intended as an indepth discussion on the occurrence or impact of natural hazards observed in the region. This is well documented elsewhere. It is intended solely to identify and highlight the range of these natural hazards to which the region is exposed and which have over recorded history of the last five hundred years, caused considerable damage to the built environment as well as loss of life. The region has so much in common with the Japanese Archipelago in respect of being similarly ravaged by a range of natural hazards, that there is much for us to learn from this area. This has meant in the case of Japan that they have developed a series of defense mechanisms to deal with survival in such a hazard prone area. These include:

1) An aggressive physical planning philosophy and strategy assist in the selection of sites for buildings of specific structures and facilities. This attempts to minimise the likely impact and hence maximise the service life of structures and facilities. Physical planning is seen as the first line of defense in the arsenal against natural hazard impact on the reduction of the service life of structures and facilities.
2) The second line of defense is where the engineers enter the picture with highly specialised technical knowledge of how structures perform when exposed to these

hazards. It involves the development and application of Codes of Practice, Specifications, Standards and proposed theories of behaviour of materials, components and structures when subjected to chemical/atmospheric assault and the effects of seismic forces and wind. These Codes of Practice are based on extensive research, simulation studies, as well as painstaking collection of field data from the historical impact of hazards on the built environment. This is the design input that reaches its high point in the development of maintenance systems and procedures. Here we must stress the development of maintenance strategies during the design or conceptualisation stage. It should not, as has been the practice, be addressed after the facility has been in service and has begun to manifest deterioration.

3) The third line of defense comes with the continuous monitoring and inspection which should rise above and beyond routine and scheduled maintenance to the level of retrofitting of structures and extending the life of the structure or facility.

Several other lines of defense have been developed to deal with the occurrence of natural hazards which focus not so much on the extending of the service life of the structures and facilities but on the protection of human life. These include 1) simulation exercises, 2) warning systems, 3) evacuation drills, and 4) the relocation of facilities. These would not be developed here in this paper since the focus of the exercise is simply the maximising of the useful life of facilities.

In respect of the structures, the essential issue is the collection of historical data on the occurrence of these hazards, the location, the frequency, the actual time period (if there is any cyclic or periodic nature of the phenomena), the extent or level of severity or intensity. This is the hazard analysis. The next issue that must be considered is the impact of the different hazards on different types of structures. We must then consider the probability of occurrence of different levels of hazards on the different types of structures/facilities to yield the possible extent of damage or deterioration of structures. This constitutes the study of risk analysis associated with the various hazards and different types of structures.

Risk = probability of occurrence of a specific level of severity x extent of damage to structure

This would suggest not only the collection of historical data of the events and the development of hazard maps for different locations, but also the derivation of the probability of occurrence of different levels of severity of each hazard. This is captured in engineering in the conceptual return period of specific events (e.g. seismic tremor of particular severity, wind speeds of specific value or rainfall of specific intensity). These are used in design calculations. This type of analysis must be carried out for the entire island and as well for the entire region.

Vulnerability studies are specific to different hazards, specific locations which combine geography and geology and specific structures or facilities. It is the interaction of phenomena with structures that must guide the vulnerability, and hence risk analysis.

Phenomena → Specific Levels of Severity → Specific Structures

We are therefore invited to carry out risk analyses before choosing sites for specific structures. Building superstructures, foundations and the full range of infrastructure systems must be the subject of these studies.

Asset Management

It is not enough to carry out the Technical Feasibility (Engineering Design), Economic Feasibility and Financial Feasibility studies before we commence construction. It is not sufficient to carry out Environmental Impact Studies. It is necessary that we conduct vulnerability analyses (studies) to establish to which hazards the particular areas are subjected. We must analyse historical data to explore the intensity and frequency of these occurrences which can be captured in hazard severity maps. We must explore the likely impacts on given elements, structures and facilities, should they be placed in that specific location.

This is not to say that we are powerless to deal with the risk. As has been identified, physical planning will present alternative sites and engineering will give engineering options which can mitigate damage. This will establish the boundaries of acceptable and unacceptable levels of damage. Risk analysis will reduce decision making to as rational a procedure as possible rather than as a question of hit and miss or surrender or accept period damage or complete destruction due to natural hazards.

Asset management must begin with the site selection for the particular asset which would depend upon the inherent vulnerability of the particular site. It must guide the design process and the selection of materials systems, components, fasteners and structures and hence the development of maintenance guides or handbooks. This in turn will determine the repair and replacement schedule.

We must extend this discussion into the very issue of the EIA. Frequently, this is an investigation into the impacts created on the environment as a consequence of the construction of the particular facility. Initially, this meant the biological and chemical impacts on plant and animal life and on the quality of the environment insofar as it may have posed a threat to the environment. And by this we concentrated on the anthropocentric defined impacts. Needless to say, this was subsequently extended to include other forms of life and to introduce the time element captured by the term sustainability with expressions of concern for generations yet unborn. This discussion was extended to include social and economic impacts, e.g. effect on traffic on the state of the economies of the related sectors. The concept needs to be extended to include the impact of the environment on the elements and structures e.g. the impact of placing structures in chemically aggressive soils, near to the marine environment or in areas exposed to cyclic changes in sunlight, ambient temperatures (industrially generated) or in localised micro-atmospheres created by gaseous or liquid effluent. These have considerable impacts on the service life of structures and facilities. In this light, asset management must also be concerned with the EIA.

Conclusions

The paper extends the dimensions of feasibility study that include or rather culminate in the acid test, vulnerability and risk analysis as a necessary tool in decision making, in respect of location of specific structures and facilities. It seeks to make decision making a rational process arguing that no structure or facility should be built, without a vulnerability analysis having been carried out. This study should be carried out ideally during the conceptualisation stage or the feasibility and not after the structure has been completed. An ex-post study of facilities should include a vulnerability study which would serve to extend the service life of any structure by allowing the owner to develop a strategy of defense.

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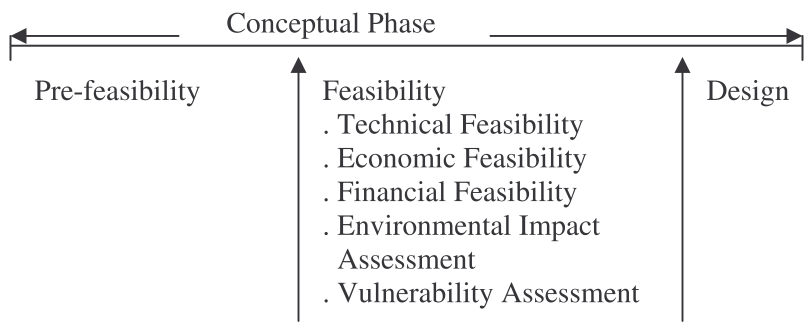

Figure 1. Conceptual phase of projects

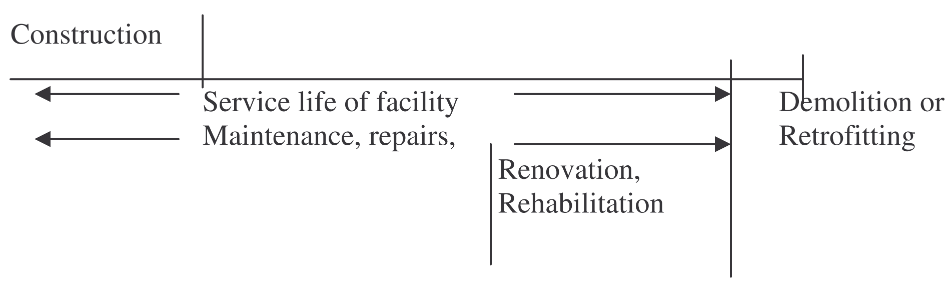

Figure 2. Post-conceptual phase of the project life cycle