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Procedia Engineering 77 (2014) 53 – 60

Procedia Engineering

www.elsevier.com/locate/procedia

Fourth International Symposium on Infrastructure Engineering in Developing Countries, IEDC 2013

Criticality Analysis of Defects in Civil Engineering Structures: Case of Onshore Process Plant.

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Abstract

In order to address maintenance need of specific structures, a criticality analysis of the structures is essential. This paper presents an analysis of experts' judgment using Analytic Hierarchy Process (AHP). Four criteria; people, assets, environment and reputation were considered as criteria. Sample representatives of Ten (10) civil engineering structures from onshore process plant were treated as alternatives. The judgment of the criteria with respect to the main goal was consistent with consistency value of 0.03. Control building (CB) was considered to be the most critical among the selected structure. Although, the technique is based on subjective experts' judgment, but is considered very important in designing maintenance plan for existing structures where design data is not available.

Peer-review under responsibility of the Accounting Research Institute, Universiti Teknologi MARA.

Keyword: Criticality analysis; Analytic Hierarch Process; onshore plants

1. Introduction

Onshore process plant is considered as a multi layered organization comprises of complex systems consisting of various types of equipment. The equipment consist of input equipment that receives row products from production

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Selection and peer-review under responsibility of the Department of Urban and Infrastructure Engineering, NED University of Engineering and Technology
doi:10.1016/j.proeng.2014.07.006

platform, processing equipment that separates and process the product, and output equipment that measures and transfer the product to either refining or exports destination. All the equipment are considered indispensable in the smooth operation and productive performance of the plants. Most often, civil engineering structure serve as a base and counter the weight and vibration imposed by equipment. The loading and vibration stresses imposed by the equipment due to extreme operating condition may likely lead to early wear and tear of the equipment's foundation This necessitates constant monitoring and inspection in order to ensure safe and reliable working condition. Any failure on the foundation or support of such system may result not only in the loss of lives and properties but also poses a serious threat not only to technical function of the plant, but also to reputation and environment [1]. Therefore, providing a sustainable maintenance strategy has become mandatory to enhance the production capacity, reputation, environmental and health and safety condition of the plants.

In line with the reasons above, various inspection and maintenance strategies are being used for the maintenance of such a system to increase the availability of the plant in one hand and to reduce the operating and maintenance cost of the plant in another hand. According to [2] industries worldwide spend a huge amount of money on maintenance of production system in an effort to maintain optimal production. Each year US industries spend a well over $300 billion on plant maintenance and operation [3]. Apparently, the cost of designing and building structures are much smaller than the cost of operating a building or other structures over the course of its lifecycle [4]. Similarly, [5] support this claim, by asserting that, the cost of maintenance itself is still rising in absolute terms and as a proportion of total expenditure. In some industries it is the second highest or even the highest element of operating costs. Hence, it is clear that much efforts is needed to enhance production, optimize maintenance cost, improve safety and remain relevant in the current competitive market. In view of the fact, the purpose of maintenance is to maximize availability and efficiency of structures and control rate of deterioration of facilities at a minimized cost [6]. Therefore, it is required to identify structure based on their critically. This will help in effective and logical prioritization of structures based on their importance in planning of any maintenance activity. However, to achieve this, there is need for simple and acceptable tool that will aid in prioritization of the structures. Therefore, the main aim of this paper is to demonstrate how Analytic hierarchy process (AHP) can be used in prioritizing some selected structures based on their criticality.

Table 1: List of Structures and their functions

Structural component	**Description of function**
Tank Bund wall	A dike wall surrounding a storage tank to serve a protection against flooding as well as spill in case the tank leaks
Receiving Pump Foundation	Foundation is the link between the structure and its eventual support, which is the soil itself. With respect to onshore plants, it provides supports for pumps.
Output Pump Foundation	Foundation is the link between the structure and its eventual support, which is the soil itself. With respect to onshore plants, it provides supports for pumps.
Access Road	A large plant must have access road to serves a link between all the units.
Control Building	Control Building, stations, Radars control tower, Jetty Satellite office and Shelters
Tank Foundation	Foundation is the link between the structure and its eventual support, which is the soil itself. It a heavy concrete structure that support tank in place.
Pipe Rack	Pipe rack might be the most important artery of any plant. It conveys the pipes and cable containers (raceways) from one equipment to another.
Open Drainage	Drainage systems (oil water sewer – manhole and surface water), effluent treatment system, basin, Road and paving.
Separation Pit	A pit usually constructed of reinforced concrete to house the oil and oil separation system.
Metering equipment support	A supporting foundation for that metering equipment. It very sensitive equipment that require stable foundation

1.1 Analytic Hierarchy Process (AHP)

The analytic hierarchy process, popularly known as AHP is multi-criteria decision making tool [7]. It is a mathematically simple tool that can be described more effectively by using matrix in the linear algebra. This technique is capable of handling a large number decision factors and provide a systematic procedure of ranking many decision variables. There are many multi criteria decision making techniques such as multi-attribute value theory (MAVT), multi attribute utility theory (MADT), multi group hierarchical discrimination (MHDIS) neural network (NN), fuzzy set theory (FS), however the study of (12) has indicated that, there is not much difference between MADT and Analytic Hierarchy Process (AHP). Similarly a study by (13) confirmed the straight forwardness of AHP. Meanwhile (14) affirmed that, AHP allows the decision makers to model a problem in a hierarchical structure showing the relationship of the goal, objectives (criteria), and alternatives. AHP was composed departing from several previously existing but unassociated techniques and concepts such as hierarchical structuring of complexity, pairwise comparisons, redundant judgments, and the eigenvector method for deriving weights and consistency considerations as shown on figure 1. According to [8] listed three steps by which all AHP analysis must passed; they are:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

1. Definition of the decision criteria to form a hierarchy of objectives. The hierarchy is structured on levels that comprises of main goal at the top, and then followed by criteria and sub criteria, while alternative and sub alternative forms the lower or bottom part of the hierarchy.

2. Pairwise comparison to determine weighs and rating. This aid in comparing two criteria at a time. It is all about how important a particular is compared to its pair

3. The next step is development of normalized eigenvector of the matrix which can be obtained by calculating priority vector to weight of the elements.

2. Methodology

Although, the entire process involved, subjective approach to decision making, the method adopted in this study has been used in number of studies to either chose an alternative, or identify a dominating criteria. Therefore, the study follows the conventional steps using analytic hierarchy process (AHP) as described below.

2.1 Decomposition of the Problem

The problem was decomposes in to a hierarchy of three levels as represented in fig.1. The upper level represents the main goal that is prioritization of civil engineering structures in onshore process plant facilities. The second level comprises of four (4) criteria; Effect on People (EP), Effect on Assets (EA), Effect on Environment (EE) and Effect on Reputation (ER) . While the lower level comprise of alternatives- structures required to be ranked. Table 2 shows the definition of the alternative structures considered in the study.

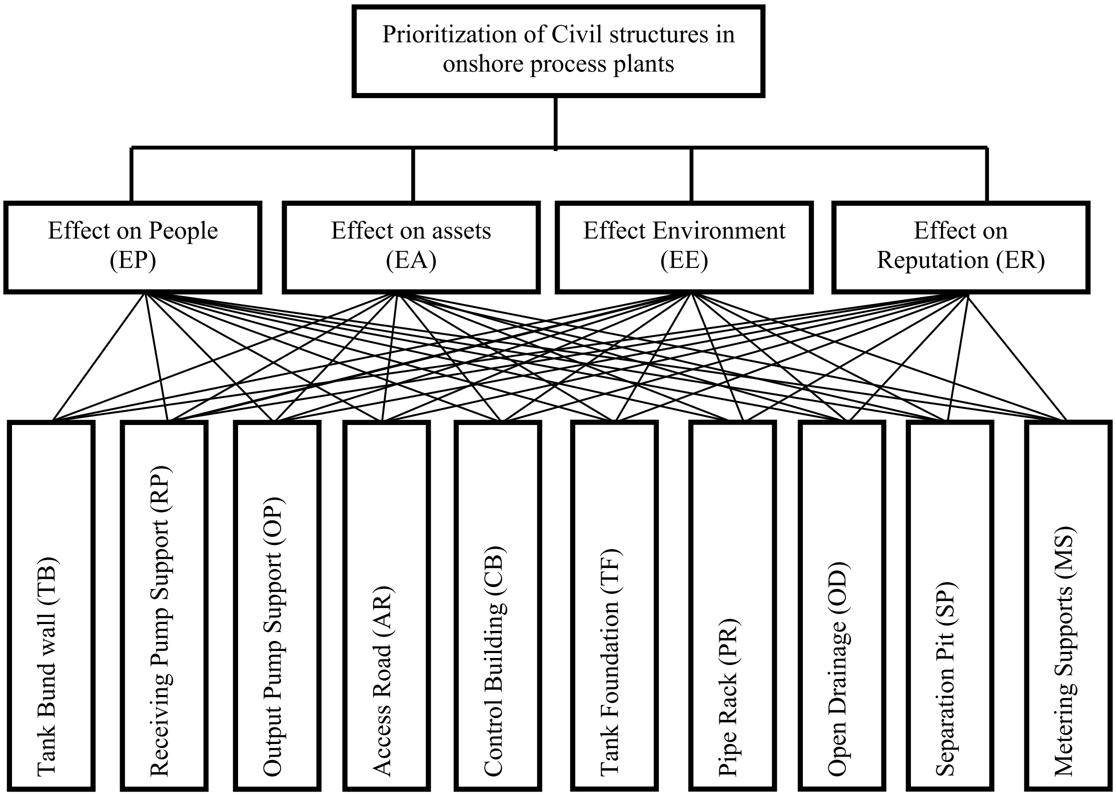

Fig.1. Decomposition model of selecting critical structure

Table 2: Definition of Criteria and Alternatives

Definition of Criteria	Definition of alternative	
Effects on People (EP)	Tank Bund wall (TB)	Tank Foundation (TF)
Effect of Assets (EA)	Receiving pump support (RP)	Pipe Rack (PR)
Effects on Environment (EE)	Output Pump Support (OP)	Open Drainage (OD)
Effects on Reputation (ER)	Access Road (AR)	Separation Pit (SP)
	Control Building (CB)	Metering Supports (MS)

2.2 Pairwise Comparison

Based on the hierarchy, a questionnaire was developed and distributed to experts in the plants. 30 questionnaires were distributed and 9 were filled and duly returned. However, one of the questionnaires was not properly filled therefore discarded. Thus, 8 questionnaires were considered in this paper.. The questionnaires were structured to elicit experts' judgment on how importance a criteria is compared to its pair. The judgment was made on a scale of 1 – 9 as opine by [7]. Table 3 shows the AHP scale used in the judgment.

Table 3. AHP Ratio Scale

Scale	Definition	Explanation
1	Equal Importance	Two alternatives contribute equally to the objectives
3	Moderate importance of one over another	Experience and judgment slightly favored one alternative over another
5	Essential or strong importance	Experience and judgment strongly favored one alternative over another
7	Demonstrated importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Extreme Importance	The evidence favoring one alternative over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromised is needed.

Based on the pairwise comparison by 8 experts, the matrix presented in table 2 was obtained. According [9] eigenvector of the comparison matrix provide best approximation to the priority ordering (weights) of the different criteria, and the eigenvalue is a measure of consistency.

TABLE 4 RELATIVE IMPORTANCE OF CRITERIA

	EA	EP	EE	ER
EA	1.00	2.12	1.54	2.63
EP	0.33	1.00	2.61	3.11
EE	0.39	0.30	1.00	1.85
ER	0.38	0.32	0.35	1.00
SUM	2.10	3.74	5.50	8.59

2.3 Calculation of Consistency Ration

Consistency in pairwise comparison matrix means that, when basic data is available, all other data can be logically deduced from them. In this study, after obtaining the local weight as shown on table 3, then the consistency ratio was obtained based on the comparative of weighs of the criteria using matrix (2). For consistency matrix, it can be illustrated as:

$$A = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \vdots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} X \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} \tag{2}$$

Where: $CI = \dfrac{\lambda_{\max} - n}{n-1}$

RANDOM INDEX OF ANALYTIC HIERARCHY PROCESS

n	3.00	4.00	5.00	6.00	7.00	8.00
RI	0.58	0.90	1.12	1.24	1.32	1.41

Therefore: $$CR = \frac{CI}{RI} \tag{3}$$

A consistency rating of 0.10 or less is considered acceptable. However, if an inconsistency has been encountered, the process of evaluation of the judgment matrix should be repeated. Perhaps, the judgment in this study proved to be consistent and therefore can be used in calculating the final hierarchy.

2.4 Calculation of the Final Hierarch

After evaluation of the alternatives based on the available criteria, the local weights of the criteria obtained in Table III can be multiplied with the eigenvalue obtained from the alternatives judgments in Table 5. This will give final hierarchy as shown on Table 6.

Table 5: Structures evaluation criteria

ASSETS	**EP (1)**	**EA (2)**	**EE (3)**	**ER (4)**
TB	0.034	0.022	0.025	0.075
RP	0.084	0.110	0.197	0.087
OP	0.181	0.207	0.188	0.153
AR	0.066	0.035	0.054	0.045
CB	0.272	0.241	0.184	0.206
TF	0.143	0.120	0.135	0.159
PR	0.061	0.020	0.059	0.080
OD	0.047	0.017	0.061	0.065
SP	0.033	0.019	0.041	0.050
MS	0.080	0.209	0.057	0.079

Table 6: The final values of the hierarchy

ASSETS	EP (1)	$\frac{EPj}{\sum_j EPj}xWj$	EA (2)	$\frac{EAj}{\sum_j EAj}xWj$	EE (3)	$\frac{EE}{\sum_j EEj}xWj$	ER (4)	$\frac{ERj}{\sum_j ERj}xWj$	Total Assets Hierarchy
TB	0.034	0.014	0.022	0.007	0.025	0.004	0.075	0.008	0.033
RP	0.084	0.034	0.110	0.035	0.197	0.033	0.087	0.010	0.113
OP	0.181	0.074	0.207	0.066	0.188	0.032	0.153	0.017	0.189
AR	0.066	0.027	0.035	0.011	0.054	0.009	0.045	0.005	0.052
CB	0.272	0.112	0.241	0.077	0.184	0.031	0.206	0.023	0.243
TF	0.143	0.059	0.120	0.038	0.135	0.023	0.159	0.017	0.137
PR	0.061	0.025	0.020	0.006	0.059	0.010	0.080	0.009	0.050
OD	0.047	0.019	0.017	0.005	0.061	0.010	0.065	0.007	0.042
SP	0.033	0.014	0.019	0.006	0.041	0.007	0.050	0.006	0.032
MS	0.080	0.033	0.209	0.067	0.057	0.010	0.079	0.009	0.118

Table 7: Final Critical Ranking

Structures	Final hierarchy	Ranking
CB	0.195	1
RP	0.140	2
TF	0.138	3
OP	0.132	4
PR	0.126	5
SP	0.083	6
ME	0.062	7
AR	0.056	8
TB	0.051	9
OD	0.028	10

3. Result and Discussion

The findings in this study, shows that control building (CB) are considered the highest critical structure in the plants. This may not be unconnected with the facts that, the entire equipment in the plant are control from these buildings. Similarly both the administrative and technical activities are being planned and coordinated from the building. Thus, considering the four (4) criteria; control building is always occupied by people; therefore, a failure on the building may lead to injury of loss of lives. Furthermore, increase competition in the global market has imposed extra challenges on oil and gas operators to ensure continues and effective supply to overcome any hindrance that may arise as a result of any failure.

The second most critical structure is receiving pump foundation. The function of receiving is pumping a specific amount of containment from the production platform to the processing area. Therefore, it operates under high temperature and pressure. The pump also suffers impact forces which induced severe vibration on its foundation. Hence, it failure may lead to total shutdown of the plant.

Based on the findings in this study, open drainage in considered the less critical civil engineering infrastructure in onshore plant. Drainage systems mainly serves as a means of evacuating run off rain, therefore even if the structure is defective, it may not affect the performance of the plant in terms of production.

Environmental related issues, particularly to oil sector are getting special attention across the world due to escalating awareness, government concerns, policy obligations as well as pressure from environmental activists. As an asset, any failure on the part of the building may affect the effective performance of the entire building. Reputation wise, the cooperate appearance of the building serves as marketing strategy. In spite of the extreme obligation, these companies are required to demonstrate their commitments towards issues that are related to environmental protection by the adoption of corporate environmental plans as well as proven efficiency within precise performance.

4. Conclusion

The paper presents preliminary findings on the criticality assessment of civil engineering structures in onshore oil and gas process plant using analytic hierarchy process (AHP). Among the four criteria considered in the study with respect to the main goal of process plant under study, the experts' judgment indicates that, effects on people as criteria scored the highest among its pairs. Therefore, it goes with the principles of safety based on global standards. While, with respect to the alternatives, control building is considered the most critical structure mainly due to its function in accommodating plants' control system and administrative personnel. The judgment is highly consistent across all the experts. Therefore, this technique is considered effective and applicable not only to structures in onshore process plants, but also to other infrastructure facilities. Therefore, there is need to extend the technique to other infrastructure like bridges and culverts.

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