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DESIGN PHASE MAINTENANCE CHECKLIST FOR STRUCTURAL DURABILITY

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Previous studies have established that early attention to maintainability during the early design stages of building projects provides for delivering high levels of comfort to building occupants and reducing maintenance budgets. This paper identifies and assesses the set of structural durability design defects that are attributed to lack of maintenance manager's feedback to the design team. The research confirmed the importance of all the identified design defects based on the assessment of the maintenance experts in the 13 public Saudi Arabian universities that operate and maintain significant building stock in their campuses. The paper presents a set of validated maintainability design review checklist for consideration by design professionals, in order to reduce the likelihood of occurrence of the identified defects. This paper serves to promote awareness among the various stakeholders in the construction industry about the earned benefits of knowledge transfer from the operation and maintenance field to the design team. It is of significant value to design professionals endeavoring on designing maintainable, cost-effective building projects; and maintenance professionals aiming to provide effective services to occupants and property owners.

Keywords: Defect, Feedback, Design development, Checklist, Guidelines.

1 INTRODUCTION

Previous studies have established that the early participation of the maintenance manager during the design development and review stages of building projects provides for avoiding the reoccurrence of design defects, and improving the maintainability of building projects (Koskela *et al.* 2002, Aris, 2006, Chew *et al.* 2008, Jensen, 2009, Bu Jawdeh *et al.* 2010, Jensen 2012, Hassanain *et al.* 2014). This paper seeks to identify and assess the set of structural durability design defects that are attributed to the lack of maintenance manager's feedback to the design team. The paper also presents a set of validated maintainability design review checklist for consideration by design professionals, in order to reduce the likelihood of occurrence of the identified defects. The methodology adopted to achieve the objectives of this research consists of three phases. The first phase involves reviewing the literature in the domain of structural systems operation and maintenance, and interviewing two experienced maintenance department managers at two public universities in Saudi Arabia, to identify the most common defects that are attributed to the design team. The second phase involves the assessment of the identified defects by maintenance experts in the 13 public Saudi Arabian universities that operate and maintain significant building stock in their campuses. The third phase involves the development and validation of a maintainability design review checklist for consideration by design professionals, in order to reduce the likelihood of occurrence of the identified defects. This paper serves to promote awareness among professionals in the construction industry about the earned benefits of knowledge transfer from the operation and maintenance field to the design team.

2 STRUCTURAL DURABILITY DESIGN DEFECTS

A group of eight structural durability defects were identified out of an extensive literature review and interviews with two experienced maintenance department managers at two public universities in Saudi Arabia. These defects typically occur due to the lack of the maintenance manager's engagement with the design team during the design development and review stages. These universities operate a substantial building stock in their campuses. The defects are presented in their ranking order. The highest-ranking defect has been listed as 2.1 and the lowest as 2.8.

2.1 Plaster Crack between Concrete Brick Joints and Wall-floor Joints

This type of cracks in interior walls is a common defect that is usually found between concrete brick joints and wall-floor joint. These settlement cracks occur due to the lack of specifying a mesh to accommodate the movement between two different elements (Chong and Low 2006, Al-Kafrawi 2011).

2.2 Damage to Underground Pipelines due to Soil or Foundation Settlement

Underground pipelines are used for water distribution or plumbing systems. These underground pipelines could be damaged due to soil or foundation settlement (Chew *et al.* 2008). The construction specifications should include clear clauses about compaction of soils in addition to provisions for conducting more soil tests before the design of the foundation system (Al- Kafrawi 2011).

2.3 Corrosion of Steel Reinforcement due to Insufficient Concrete Cover

Insufficient concrete cover allows the corrosion of steel reinforcement, which leads to concrete cracking and spalling (Chew *et al.* 2004). Sufficient concrete cover, detailing of joints and concrete mix contribute effectively in the development of high performance, low maintenance slabs (De Silva and Ranasinghe 2010). Other contributing factors to the corrosion of steel reinforcement include high permeability of concrete caused by low water cement ratio, specification of reinforcement bar that could easily corrode in hot humid climates and seepage of water from floor drainage in concrete slabs (Chew 2010).

2.4 Cracks in Floor Slabs, Walls, and Tiles due to Differential Settlement

Differential settlement of structures most likely occurs due to expansive clay. These settlements result in the development of significant structural cracks in walls and floors. The occurrence of these cracks could be alleviated by conducting more soil tests (Chong and Low 2006). Cracks caused by differential settlement occur in virtually all types of façade including: masonry walls, pre-cast concrete cladding, plastered walls, tile cladding, and natural stone cladding (Chew 2010). The scale and severity of the cracks are affected by the exposure to the climatic conditions where the building is located (De Silva 2011).

2.5 Tile Dependence, Adhesive Failure, Cracks and Fraction at Weak Points due to Expansion and Contraction Stresses

Thermal movement can cause many defects such as fraction at weak points, cracks in plaster, and adhesive failure and tile dependence. These defects lead to water penetration in walls and roofs (Ishak *et al.* 2007). This defect typically occurs due to inappropriate design of expansion joints in addition to the regular expansion and contraction (Chong and Low 2006, Chew 2010).

2.6 Moisture and Dirt Infiltration through Expansion Joints due to Inefficient Filling Materials and Sealant

Expansion joints should be filled with insulating materials. Waterproofing at floor level should be added. Sealant would then be applied to seal potential moisture infiltration. This will eliminate the development of stains and cracks caused by moisture and dirt infiltration through expansion joints (Chong and Low 2006, Al-Kafrawi 2011).

2.7 Moisture Penetration in the Basement at Beam-wall Joints, Walls, and Ceiling-wall Joints due to Insufficient Waterproofing and Insulation

Cracks in basements are usually noted at the construction joints between beams and walls as well as on the joints between ceilings and walls. These cracks are caused by failure to accommodate the settlement of soil (Al-Kafrawi 2011). With the lack of provision of a waterproofing membrane, these cracks may provide a channel for water seepage (Chew 2010).

2.8 Cracks around Columns and Beams due to Inadequate Structural Design

Cracks appear in columns and beams after a period time once the building undergoes operation. These cracks occur due to inappropriate structural design of these elements (Al-Hammad *et al.* 1997). Proper specifications of concrete mix and adequate detailing of the structural elements have the potential to minimize the occurrence of cracks (De Silva and Ranasinghe 2010). These cracks appear due to thermal movement between steel and concrete, and inadequate design for deflection occurrence (Chew 2010).

3 ASSESSMENT OF THE STRUCTURAL DURABILITY DESIGN DEFECTS

Assessment of the identified eight structural durability design defects was conducted, shown in Table 1, by an experienced group of maintenance department managers at 13 long established public universities in Saudi Arabia. The participants in the study acknowledged the occurrence of these defects due to the lack of involving the maintenance manager during the design development and review stages. A questionnaire survey was developed including the identified defects. The participants were requested to assign one out of five evaluation terms to indicate the importance level of each design defect. These terms were "Extremely Important" (EI), "Very Important" (VI), "Important" (I), "Somewhat Important" (SWI), and "Not Important" (NI). The importance index for each defect was calculated as follows (Dominowski 1980):

$$\text{Importance Index (I)} = [\sum (a_i)(x_i) / 4\sum x_i] \times 100\% \quad (1)$$

where a_i is the constant representing the weight assigned to i; and x_i is the variable representing the frequency assigned to i. The response for i is 0 to 4, as follows:

- x_0 = frequency of "Extremely Important" response corresponding to $a_0 = 4$.
- x_1 = frequency of "Very Important" response corresponding to $a_1 = 3$.
- x_2 = frequency of "Important" response corresponding to $a_2 = 2$.
- x_3= frequency of "Somewhat Important" response corresponding to $a_3 = 1$.
- x_4 = frequency of "Not Important" response corresponding to $a_4 = 0$.

The following scale was devised to establish the importance level for each defect:

- If the index is below 12.5%, the defect is "Not Important".
- If the index is between 12.5% and 37.5%, the defect is "Somewhat Important".
- If the index is between 37.5% and 62.5, the defect is "Important".
- If the index is between 62.5% and 87.5%, the defect is "Very Important".
- If the index is above 87.5%, then the defect is "Extremely Important".

Table 1. Assessment of structural durability design defects.

No.	Maintenance Challenges Attributed to the Lack of Maintenance Feedback to the Structural Design Team	Importance Index (%)	Level of Importance
1.	Plaster crack between concrete brick joints and wall-floor joints.	77.08	VI
2.	Damaged underground pipes due to soil or foundation settlement.	72.92	VI
3.	Reinforcement corrosion due to insufficient concrete cover.	70.83	VI
4.	Cracks in floor slabs, walls, and tiles due to differential settlement.	68.75	VI
5.	Tile dependence, adhesive failure, cracks and fraction at weak points due to expansion and contraction stresses.	66.67	VI
6.	Moisture and dirt infiltration through expansion joints due to inefficient filling materials and sealant.	66.67	VI
7.	Moisture penetration at beam-wall joints, walls, and ceiling-wall joints due to insufficient waterproofing and insulation.	60.42	I
8.	Cracks in columns and beams due to inadequate structural design.	54.17	I

The assessment results indicated that all of the identified design defects were assessed as very important, or important. The authors are in agreement with the obtained results, as these defects would require costly repairs. The authors also predict that the engagement of the maintenance manager with the design team during the design development and review stages would eliminate, or at least reduce the occurrence of these defects during the service life of buildings.

4 MAINTAINABILITY DESIGN REVIEW CHECKLIST

Table 2 presents a set of validated maintainability design review checklist for consideration by design professionals, in order to eliminate, or at least reduce the likelihood of occurrence of the identified defects. The checklist is composed of eight guideline statements. The developed guidelines were assessed by the survey participants, who assessed the identified structural durability design defects. The guidelines were evaluated as either extremely important, or very important. The guidelines are presented in ranking order according to the value of their importance indices.

Table 2. Assessment of the maintainability design review checklist.

No.	Maintainability Design Review Checklist for Structural Durability	Importance Index (%)	Level of Importance
1.	The specifications provide for appropriate fireproofing and firestopping materials in the design.	91.67	EI
2.	The specifications provide for adequate concrete cover for the steel reinforcement as specified by codes.	87.50	EI
3.	The specifications provide for a mesh between concrete brick joints and floor wall joints to avoid any future cracks.	85.42	VI
4.	The design provides for expansion joints when the length of the building exceeds that length specified by the codes	81.25	VI
5.	The results of the soils bearing capacity tests are taken into consideration in the design of the foundation system.	79.17	VI
6.	The design provides for the required strength, thickness, and fire resistance rating of building construction materials	68.75	VI
7.	The specifications provide for a full soil compaction (if required) to avoid future settlement.	68.75	VI
8.	The design provides for strict specifications for the procurement of concrete.	66.67	VI

5 CONCLUSIONS

Previous studies have established that early attention to maintainability during the early design stages of building projects provides for delivering high levels of comfort to building occupants and reducing maintenance expenditures. This paper identified and assessed the set of structural durability design defects that are attributed to lack of maintenance manager’s feedback to the design team. The research confirmed the importance of all the identified design defects based on the assessment of the maintenance experts in the 13 public Saudi Arabian universities that operate and maintain significant building stock in their campuses. The paper presented a set of validated maintainability design review checklist for consideration by design professionals, in order to eliminate, or at least reduce the likelihood of occurrence of the identified defects. The study serves to promote awareness among professionals in building projects about the benefits of knowledge transfer from the operation and maintenance field to the design team.

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