Impact on the Design Life of Buildings in a Tropical Hot Wet Environment

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ABSTRACT

The degradation of the built environment is an enormous economic and environmental problem. Knowledge about the exposure environment and its relationship with the degradation of various building materials is very much needed, particularly in the tropical belt as a basis for proper maintenance and service life planning. The rate of degradation is directly affected by the macro, meso and micro environments and these are specific to geographic location. This paper considers the impact of the hot-wet tropical environment in Malaysia on life cycle degradation factors affecting buildings. Particular reference is made to an in depth investigation of a 50 year old hospital undertaken in 1988 in the southern town of Johor Bahru. The hospital had suffered structural and durability failure arising from a lack of timely maintenance intervention. A remedial approach developed based on assumed future usage patterns taking into consideration monitoring and maintenance requirements is highlighted. The need for a better characterization of key environmental degradation factors and the development of a more rational approach to the design are also considered.

KEYWORDS

Hot-wet Tropical Conditions, Servicability – Life Cycle Degradation , Durability Assurance, Concrete Failures

1 INTRODUCTION

There has been an increasing recognition for the need to forecast and control the cost of building and infrastructure ownership, because a high proportion of the life cycle costs of a facility may be set at the time of completion. Service life planning aims to reduce the cost of ownership. An assessment of how long each part of a structure will last; helps to decide the appropriate specification and detailing. When the service life of a structure and its parts are estimated, maintenance planning and value engineering techniques can be applied. Reliability and flexibility of use can be increased and the likelihood of obsolescence reduced.

To safeguard the built environment; action is urgently needed. In principle, there are two possibilities. Firstly, society should try to improve the environment surrounding the materials and secondly, better products, processes, methods and standards should be developed. The first action is being pursued by the environmental research area particularly in the developed economies but not exclusively. In Malaysia for instance there have already been moves in the last 5 years to take a more proactive approach to environmental pollutants. An international standard (ISO 15686-2001 (1) in design life of buildings is currently being developed under ISO/TC59/SC14 and this forms a basis for a more rational approach to service life planning.

A critical requirement for a proper approach to design planning is an understanding of the key environmental degradation factors which affects durability. This coupled with a planned maintenance approach should be the basis for future management of the built environment. There is only a limited consideration of these factors in the tropical belt countries and this paper attempts to put together some real life data for further consideration.

2 CHARACTERIZATION OF KEY ENVIRONMENTAL DEGRADATION FACTORS

The main sources of information used to classify the environment were obtained from the meteorological services and presented in full elsewhere [Gurusamy, K., 2004].

The characteristic features of the climate of Peninsular Malaysia are uniform temperature, high humidity and copious rainfall and they arise mainly from the maritime exposure of the country (see Fig. 1). Climatological records show that the humidity in the Klang Valley and its surroundings remain almost constant throughout the year with annual mean of 83.4% which is 6% higher than in UK and Hong Kong. However, the mean values hide the fact that the humidity is in the range 50-70% at between 7-8 hours daily which is the optimum range of values for carbonation. The annual mean maximum is 98.0% and the annual mean minimum is 55.7%. While there are local variations throughout the country this is not considered significant enough for the assessment of durability.

The mean annual rainfall and solar radiation shown in Fig. 1 are typical for Peninsular Malaysia. The Air Pollutant Index (API) has been regular recorded since 1996. A comparison between the API for Kuala Lumpur (Inland Urban), Johor Bahru (South Coast Urban), Seberang Prai (Industrial) and Kuantan (East Coast Urban) is also given in Fig. 1. Kuala Lumpur the capital city with its high volume of traffic is generally the more polluted environment compared for instance to the Industrial district of Seberang Prai. This is related to the considerably higher levels of vehicular emissions in the Klang Valley. The measure of SO_2 confirms that the worst affected areas are where there is a concentration of industries (ie) in Johor in the South (32 $\mu g/m^3$) and Seberang Perai in North. (23 $\mu g/m^3$). Actual data on Carbon Dioxide concentrations is not presently available however an examination of the carbon monoxide measurements indicates that the urban concentration was 2.5 to 3 times the background concentration during the period 2000 – 2003. The equivalent figures for the

Industrial Environments is 2.0 to 2.5. This does suggest that carbonation damage is likely to be accelerated in the Urban and Industrial locations in Malaysia. This requires further consideration based on field data.

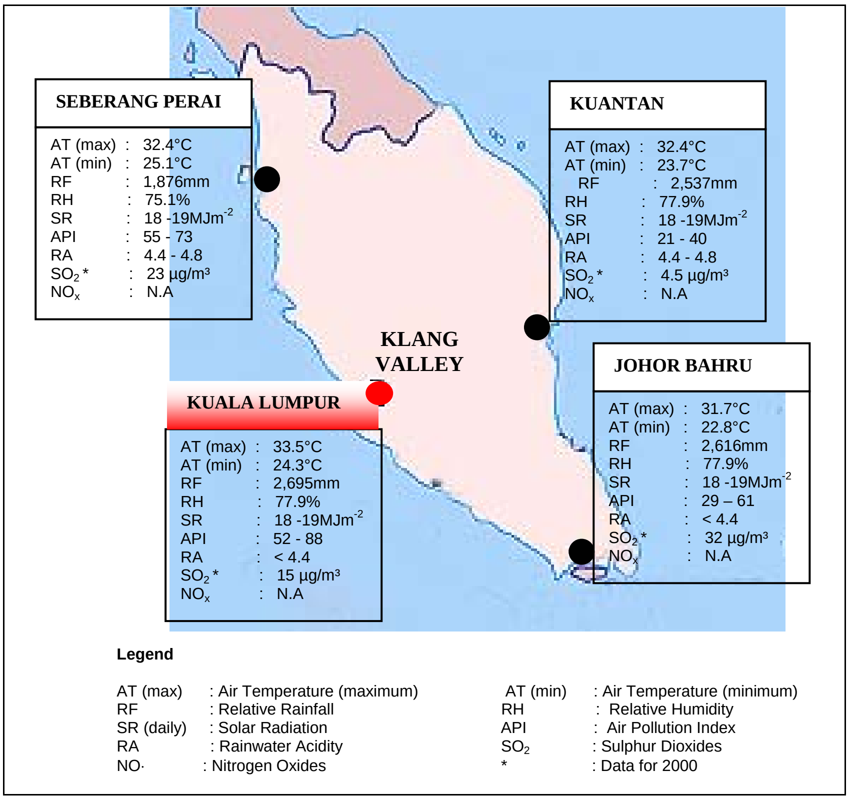

Figure 1: Environmental Characteristics for selected locations, Peninsular Malaysia, 2002.

Peninsular Malaysia is surrounded by oceans (i.e.) the Malacca Straits (West), the Johor Straits (South) and the South China Sea (East). Sea spray may be regarded as a form of particulate pollution which can travel under the influence of wind for several kilometers inland, from coastal areas but rapidly decreases with distance from the coast. This is also the case in Peninsular Malaysia with the most significant effects in the North East and East of the Peninsular as the South and West are much more sheltered by adjacent land masses (i.e.) Singapore and Sumatra respectively.

The general Malaysian environmental characteristics are compared to relevant southern European data [ISO 15686 2004] in Table 1. Generally this indicates that more severe macro environmental conditions for building component deterioration exist locally. The choice of sealants, external cladding materials and architectural finishes in buildings are therefore likely to have reduced service life and requires further systematic documentation and examination.

1	**Temperature**			**ISO 15688-7 from Annex A For Europe**		**Malaysian Climatic Condition**	
	Category 3	Hot	a) Ave. Temperature b) Max. Temperature c) Min. Temperature	> 35ºC - -		NR 33ºC 24ºC	
2	**Rainfall Humidity**						
	Category 4	Very humid	a) Rainfall (mm/year) b) Humidity (average yearly 9 am RH)	>1300mm/year > 80%		1800 -3000 mm/year 75.1% - 84.7%	
3	**UV Radiation**						
				Moderate	Severe	Moderate	Severe
			a) Annual radiation on horizontal surfaces	< 5 GJ/m^2	≥ 5 GJ/m^2	NR	5.8 – 6.9 GJ/m^2
			b) Average temperature of the warmest month of the year	< 22°C	≥ 22°C	NR	≥ 32°C

NOTE: NR - Not Relevant.

Table 1: Comparative Analysis of macro/meso environmental conditions in Malaysia with reference to Annex A Guiding Supplement in ISO 15688-7 given for Europe.

3 CASE STUDY – INVESTIGATION OF A GENERAL HOSPITAL IN JOHOR BAHRU

3.1 General Background

The present author [Robery, P. C., et al., 1988] was closely involved with the Consultancy services for the remedial and rehabilitation works for the main block of the Hospital Sultanah Aminah (HSA), Johor Bahru, which commenced on 1st December 1988. The hospital is located in Johor Bahru, approximately ¼ kilometer north of the Straits of Johor (see Fig. 2).

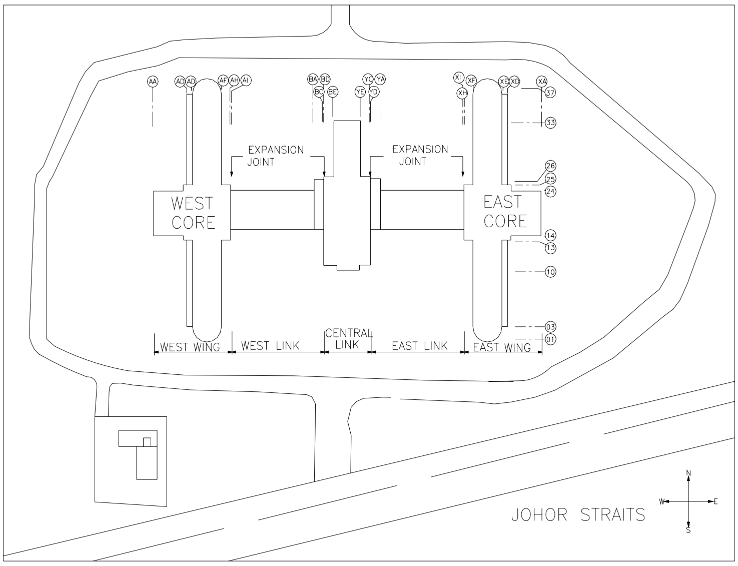

Figure 2: Hospital Sultanah Aminah, Johor Bahru – Location plan at the time of investigation (1988)

The structure is a 6 storey reinforced concrete frame with reinforced concrete pile foundation and a brickwork facade. Construction started in 1938 and was completed in 1941. The ground floor is a reinforced concrete suspended slab below which is a basement. The total cost of the building when the structure was completed in 1941 was estimated to be RM 2,057,075 (USD 541,382). This is equivalent to RM 15,811,900 Million (USD 6,176,520) taking into consideration inflation and the value of money in 1993.

3.2 Initial Overview

The structural investigation involved three distinct areas of interest (ie) the reinforced concrete frame, external brickwork facade and flat roof areas and the soils and external works.

The reinforced concrete columns and beam/slab floors showed some signs of deterioration in the visual form of cracks and spalls. The worst deterioration was in the ground floor soffit beams. It had been reported [PWD, 1987] that cracking in the beams supporting the ground floor was first observed in the 1950’s and as a result, a layer of gunite was applied to the beams and the soffit of the suspended ground floor slabs.

The soil condition was considered to have an obvious impact on the stability of the building. The unknown foundation condition, close proximity to the Straits of Johor and original swampy land necessitated a thorough soil investigation. The groundwater drainage system was a significant conduit for sea water ingress in basement areas during high tides resulting in the durability failure of reinforced concrete.

The structural integrity of the building required checking as a result of the reinforced concrete deterioration, changing use/loadings within the building and to account for the differences in design criteria between the 1930’s and 1980’s. The full details of the structural investigation are given in a previous paper [Gurusamy, K. 2004].

A general view of the building during the remedial works contract is given in Photo 1.

3.3 Durability Considerations

3.3.1 Introduction

A full assessment of material durability is based on a visual examination of selected parts of the HSA with further testing and analysis undertaken to characterize the long term deterioration of different elements of the structure. Only carbonation of structural elements is discussed below. All other elements and chloride ingress mechanisms are discussed elsewhere.

3.3.2 Depth of Cover and Carbonation

As part of the breakout operations and the taking of core samples, the depth of carbonation of the concrete was measured using phenolphthalein ph indicator. These data were compared with the depths of cover at the corresponding locations. The results are summarized below.

Depth of Carbonation

Carbonation of the reinforced concrete proceeded at two rates:

- in the damp, gunite covered basement elements, carbonation depths were negligibly low in well compacted concrete,
- in the dry superstructure, carbonation depths were high and variable.

The exception to the above, was in honeycombed areas of concrete in the ground floor beam soffits. It was noted that in approximately 94% of areas where corrosion had reduced the cross-section of the reinforcing bar, the concrete was severely honeycombed. The bar would consequently have been unprotected from the basement environment since the time of construction. Similar results were found in cores from ground floor slabs, suggesting 80% of the soffit was honeycombed.

Carbonation and Cover in the Superstructure

Average depths of cover measurements were made for the main steel around the superstructure. The data is summarized in Table 2 below.

Element	*Ave. Max Depth of Carbonation*	*Ave. Depth of Cover*
Beam	40 mm	40 mm
Column	40 mm	45 mm
Slab/Canopy	50 mm	19 mm

Table 2: Maximum Depth of Carbonation Vs Average Depth of Cover.

The results showed a significantly lower cover was used in the slabs. Consequently, based on average depths of carbonation, the majority of the slabs had carbonated past the depth of the bar. As these are average values, there are localized areas of corrosion, initiated by greater than average (or less than average) cover.

Carbonation and Strength

Good correlation was found between carbonation of the superstructure and estimated insitu cube strength. For the typical superstructure strength range of 20 – 29 Mpa, a carbonation coefficient was calculated from which the average carbonation rate for that strength range could be calculated. This gave the average depth of carbonation as 51mm after 50 years. In a further 50 years, assuming conditions in HSA do not change (ie, paint types used, change of use/ventilation of rooms), the average depth of carbonation was estimated to be 72mm.

For the beams and slabs at ground floor level, the low depths of carbonation were due to the combined affects of higher compressive strengths (average of 34 Mpa and 40 Mpa respectively), the gunite protective layer and the high humidity which reduced carbonation rates.

Carbonation and Corrosion - Corrosion of the superstructure was not as widespread as would be expected for the high depths of carbonation measured around HSA. This is due to the lack of moisture at the depths of the bar which had restricted the corrosion process. The continued integrity of the structural elements depended upon the concrete being kept free from both water and high relative humidity. This was confirmed by the electrochemical potential data, which showed that areas of damp concrete adjacent to areas of leakage are active and liable to corrode.

Only in the basement environment in areas of honeycombed concrete were widespread areas of corrosion found.

3.3.3 Reinforcement loss of Section – Ground Floor Beams

From the visual survey it was identified that extensive spalling of basement beams had occurred due to reinforcement corrosion. This was due to carbonation of concrete to full depth of steel at the cover zones which was extensively honeycombed. A total of 54 ground floor beams had the bottom main reinforcement exposed to determine the loss of reinforcement section by steel corrosion. Every fourth beam was selected plus other beams which visually exhibited corrosion related defects. The results are shown in Table 3. A total of 42% of the main reinforcement had lost 10% or more of the cross-sectional area.

Loss of Cross Sectional Area	Number of Bars Measured	% of Total
< 10%	53	58 %
10-20%	21	23 %
>30%	15	17 %
	2	2 %
Total	91	100 %

Table 3: Reinforcement loss of section – ground floor beams

3.3.4 Future Usage – Environmental Considerations and Maintenance Approach

The Malaysian environment is characterized by high temperatures (Average 27 °C), and humidity (84% RH) which are fairly constant throughout the year with distinct wet and dry seasons. While the macro environmental factors are important it is the micro-climates specific to the structure which have a significant impact on the durability and service life of the building.

The effects of moisture content, greater than 4%, on reinforcement corrosion was confirmed during the investigation. In the basement east link beams, for example, where serious corrosion was found (up to 25% loss of steel section), the moisture contents were measured at values greater than 10%. This was attributed to the effects of condensation, as the ground floor area was air conditioned and kept at a much lower temperature than the basement.

The effect of leaking services on visual deterioration was evident throughout. These included water stains, rust stains, algae and mould growth, plant growth, brick swelling and cracking, so on. The problem was particularly acute where plumbing was built in and covered by brickwork.

The overall aim, therefore, for future usage of the hospital was to eliminate all forms of wetting of concrete surfaces. This included moisture penetration from whatever source, such as defective brickwork, leaking service pipes, failed roof waterproofing or washing down of porous walls and floors. Structural elements enclosing air conditioned areas would be subject to potential condensation, the critical zone being reinforced concrete members with air conditioning only on one side leading to a temperature gradient sufficient to produce condensation.

By taking a strategic approach to maintenance planning (ie) special attention to control and monitoring at wet areas, it was possible to focus the remedial works on removing potential sources of moisture and water penetration and limiting the extent of structural remedial works to elements which had visible corrosion damage. All other elements which were carbonated beyond cover provisions and potentially in danger of corrosion damage were left untouched with a provision that regular monitoring and maintenance is undertaken. In this way the full cost of the remedial works was capped.

4 COMPARISON OF MALAYSIAN CARBONATION DATA TO EUROPEAN RESEARCH

Considerable data had been gathered as part of a European funded research programme undertaken by Taywood Engineering (M) where a comprehensive review of carbonation data had been undertaken resulting in design life prediction curves. These results for carbonation penetration are summarised in Table 4 and compared to local Malaysian data. The carbonation data discussed from Johor Bahru fits well into the European data range for 30 and 40 MPa concrete for interior exposure. Due to the higher temperatures in Malaysia, approximately 10°C higher on average compared to UK, a doubling in penetration rate would have been expected based on the Arhenuis law. This appears not to be the case most likely due to the higher relative humidities typical of Malaysia and the fact that concrete will not have sufficient time to dry out in the 7-8 hours where the RH is between 50-70% over a 24-hour period. The Malaysian results are however on the higher side of the predicted curve (see Fig. 3). It should also be noted that the rate of carbonation will depend on variability in the local materials used for the concrete production and the efficiency of concrete curing.

Source of Data	**'k' mm(year) ½**		**Time for Carbonation Font to reach steel (years)**		
		Cover Depth	**25 mm**	**35 mm**	**40 mm**
HSA (Grade 30 - 39	5.8(1)		19	36	48
HSA (Grade 40+)	4.9(2)		26	51	67
European data (Grade 50)	2.9(3)		74	145	190
Malaysian data (Grade 50)	4.0(4)		39	76	100

Note: (1) Johor Bahru Data, Hospital Sultanah Aminah
(2) Johor Bahru Data, Hospital Sultanah Aminah
(3) 'k' value based on design curve for European conditions (see Fig. 3)
(4) 'k' value corrected for Malaysian conditions (see Fig. 3)

Table 4 : Depth of carbonation based on diffusion coefficients (k) obtained from insitu testing in Johor Bahru compared to European data .

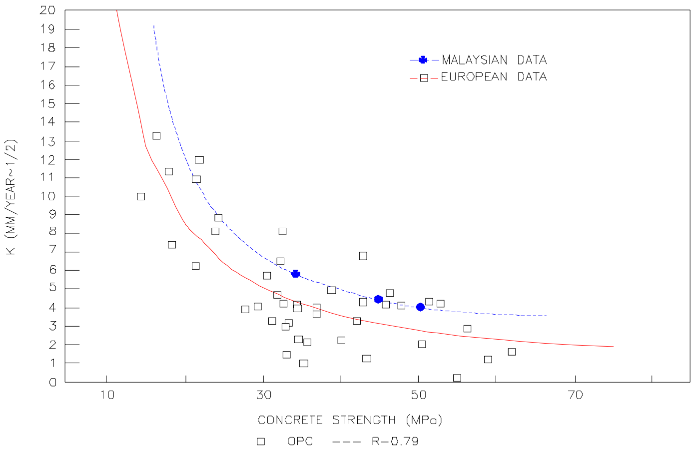

Figure 3: 'k' vs 28 days concrete strength – Interior Environment for European and Malaysian conditions.

5 OVERVIEW OF LIFE CYCLE DETERMINATION

The case study effectively illustrates the Environmental Impact on a 50 year old structure in a coastal hot humid tropical setting. The data gathered confirms the well known effects of carbonation and chloride penetration on reinforcement corrosion. However despite the generally more onerous environmental conditions compared to equivalent data from the United Kingdom the time to damage while accelerated has not increased as expected based on Arhenius Law. In relation to carbonation penetration this appears to be probably due to the higher relative humidities typical of the tropical belt countries and the insufficient time for concrete to dry out. The paper also highlights the importance of timely maintenance intervention to achieve service life expectations. A timely intervention to deal with expected component failure for example of the flat roof areas or leaking down pipes or the application of coatings to protect against carbonation and chloride ingress related corrosion and brickwork damage could have reduced substantially the RM 25 million (USD 6,579,508) remedial and upgrading programme which became necessary in the early 1990’s.

It was also confirmed that Airbourne chlorides were not a problem in this southern coastal region probably because of the sheltered nature of the Johor Straits which has Singapore as a protective land mass to the south. Carbonation of concrete was well beyond cover provisions and this requires consideration during design for unsheltered concrete elements where the availability of moisture will lead to corrosion. Guidance in this regard involves the use of minimum concrete grades and minimum cover provisions based on design life requirements and can be readily be modelled using the data presented herein for the climatic conditions typical of a hot wet tropical setting.

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REFERENCES

BS 8110, British Standards Institution – 1985 "*Structural Use of Concrete*"

CP114 British Standards Institution - 1948 "*British Standard Code of Practice for the Structural use of Normal Reinforced Concrete in Buildings*",

Gurusamy, K. and Browne, R. D. February 1994, "*Life Cycle Cost Design for Buildings & Structures : A Strategic Initiative*", Presented at MIGHT forum on the Construction Industry, Kuala Lumpur, Malaysia

Gurusamy, K. June 1994, "*KL-LRT Precast Viaduct Elements, Long Term Durability For 100 Years Design Life" Report 1303/94/6851*

Gurusamy, K. July 1999, "*Concrete Durability In Malaysia – A Much Needed Reassessment*", Presented at the Cosett'99, Sixth International Conference on Concrete Engineering and Technology Seminar, Kuala Lumpur, Malaysia ,

Gurusamy, K. Sept 2004, "*Environmental Impact On The Design Life Of Building In Malaysia*", Presented at the International CIOB Construction Conference, Kuala Lumpur, Malaysia,

Robery, P. C. , Currie, R. , Gurusamy, K. and Sinclair, T. June 1989, Hospital Sultanah Aminah Johor Bahru, Interim Report No 2, Report 014H/89/4019,

Haagenrud, S.E. and Henriksen, J.F. 19-23 May 1996, *Degradation of built environment – review of cost assessment model and dose-response functions,* Proceedings of the Seventh International Conference on Durability of Building Materials and Components, 7DBMC, Stockholm, Sweden, – Volume 1.

ISO 15686 Buildings and Constructed Assets – Service life planning Parts 1-8, at various stages of publication.

PWD 1987, Construction Unit, Design and Research Branch P.W.D. Headquarters, Kuala Lumpur Preliminary Report on the Defects at Sultanah Tun Aminah Hospital, Johor Bahru (Translated copy), Internal Publication

The Institution of Structural Engineers, July 1980, "*Appraisal of Existing Structures*".