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Durable Parking Structures: a Level of Service Approach

Durabilité des structures de garages: une approche du niveau de service

Dauerhafte Parkhäuser - ein Ansatz zum Gebrauchsniveau

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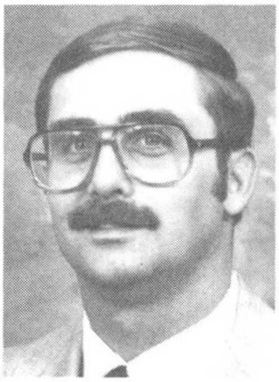


Ken Napior, born in 1950, earned an architectural engineer degree at the California Polytechnic State University, San Luis Obispo, CA. He specialises in the design and construction of post-tensioned and reinforced concrete buildings. He has extensive experience in design, construction, and investigation.

SUMMARY

This paper presents a new approach to selecting design criteria based on desired level of service. Selecting the proper criteria can mean the difference between a happy or disappointed client. For instance, the engineer can estimate the slab thickness based on experience. Using this estimate, he can select a slab thickness thicker or thinner, based on the severity of the exposure, location of the project and budget. No one set of design standards is suitable for all situations.

RÉSUMÉ

Cette communication présente une nouvelle approche du choix des critères d'étude qui dépendent surtout du niveau de service désiré. La justesse d'une telle sélection détermine le degré de satisfaction ou de contrariété du maître de l'ouvrage. Ainsi, l'ingénieur peut choisir l'épaisseur d'un plancher en fonction de son expérience. Partant de là, il peut la prévoir plus ou moins grande, selon les conditions de service, la situation de l'ouvrage et le budget dont il dispose. De ce fait, aucune règle générale de projet ne peut répondre à chaque situation particulière.

ZUSAMMENFASSUNG

Im Beitrag wird ein neuer Ansatz zur Wahl von Entwurfskriterien vorgestellt, der auf dem gewünschten Gebrauchsniveau beruht. Die richtigen Kriterien zu finden kann den Unterschied zwischen einem zufriedenen oder enttäuschten Bauherrn ausmachen. Zum Beispiel kann der Ingenieur die Deckendicke nach seiner Erfahrung wählen. Von diesem Anhaltspunkt aus kann er die Decke dicker oder dünner gestalten, je nach Grad der Umwelteinwirkungen, der Lage des Bauprojekts und des Kostenziels. Kein einzelner Satz von Entwurfsanforderungen ist für alle Situationen geeignet.

1. INTRODUCTION

This paper presents a new approach to selecting design criteria based on desired Level of Service. Selecting the proper criteria can mean the difference between a happy or disappointed client. For instance, the engineer can estimate the slab thickness based on experience [12]. Using this estimate, they select a slab thickness thicker or thinner, based on the severity of the exposure, location of the project and budget. No one set of design standards is suitable for all situations[1,9].

2.0 LEVEL OF SERVICE

Traffic engineers developed a system of classifying flow conditions by Level Of Service (LOS). Signalized intersections where traffic is virtually free flowing represents LOS A, the highest level of service. As congestion increases, the level of service decreases. The lowest, LOS F, results in gridlock. Traffic conditions are considered least acceptable for design purposes with LOS D. At this level, delays occur, but are acceptable to regular users.

The LOS concept for the functional design of parking structures was developed by parking consultants in the 1980's [7]. Structural engineers can now apply the level of service concept to selection of the structural criteria, that affect long term performance and durability.

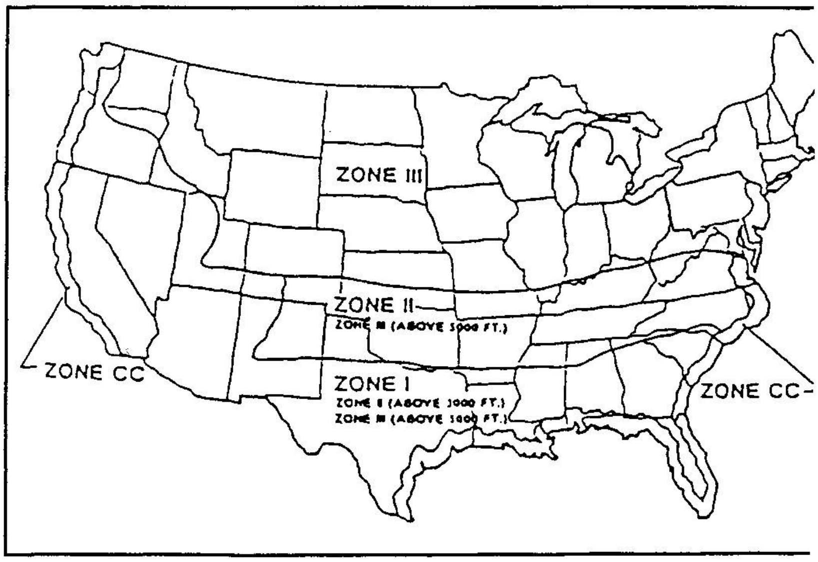
The structural shell for a parking structure is approximately 45 percent of the total building cost [5]. The criteria selection in the schematic phase affects the initial cost and maintenance costs of the structure[7,8]. Owners know that the initial and future values of the project depend upon knowledgeable choices. However, until now, there was no quantitative way to assess the level of service of the design criteria.

3.0 EXPOSURE

In the United States, five exposure zones are suggested [5] to assist in identifying exposure conditions, Figure 1).

Zone I: Areas with the mildest conditions and neither freezing nor salt is present.
Zone II: Areas where freezing occurs and de-icing salts are never or rarely used.
Zone III: Areas where freezing and de-icing salts are common.

Coastal Chloride Zone I, (Zone CC-I) Areas in Zone I and within 10 miles of a major body of salt water.
Coastal Chloride Zone II (Zone CC-II) Areas in Zone I, and II that are within one half mile of a major body of salt water.



Climates can range from mild exposure to an extremely harsh environment, with large fluctuations of temperature. Chemical attack by de-icing salts is a major concern [2]. Where salt is commonly used on roads and in parking structures, the engineer must account for the increased risk of corrosion. Chloride penetration has been a major catalyst for the onset of deterioration [12,13].

4.0 DESIGN, DETAILING, AND MATERIAL SELECTION

Proper selection of material, detailing and construction practices, affect the durability of the parking structure. Consideration must be given to adequate drainage, detailing for volume changes, material selection and finishing, etc. [1,10]. These criteria are shown in Table 1 [8]. The engineer selects criteria within the budget and durability requirements of his/her client. Thus, the cost of the project is based on quality of the material specified, labor costs, and geographic area.

5.0 DURABILITY ANALYSIS

An approach to assess mathematically the LOS of a slab has been developed by the author. Selections are made from a list of 26 design criteria, see Table 2. An LOS rating is assigned to each criteria. The rating system for some criteria is based on quantity. For example, in a severe climate area, air entrainment may vary from 0 to 7%. A value of 0 and 7% is assigned LOS F and A respectively. The LOS rating for other items is based on their inclusion. For example, water cured concrete is rated LOS A in both a mild and severe climate. If the slab is not water cured, then LOS C is assumed in a mild climate zone, and LOS D in a severe climate zone. The severity of exposure of the structure directly affects the LOS rating.

The relative value of each selection is based on its degree of importance to the overall system. For instance, epoxy-coated reinforcing has a larger relative value than the lateral load carrying system in a severe climate zone for seismic zone 1 and 2. However, in a mild climate zone in seismic zone 4, epoxy coating has a lower relative value than the lateral load carrying system. In a mild climate zone, criteria that are not required, such as corrosion inhibitors, epoxy-coated reinforcing, etc., are non-rated, since their contribution to durability is minor.

The relative importance of some criteria increases, if other complimentary criteria are excluded. This is reflected in the overall LOS rating for the floor system. Omitting epoxy-coated reinforcing becomes significant in a severe climate zone, if criteria such as corrosion inhibitors or sealers are excluded. Thus, the relative value of each criteria is affected by the total selection of the concrete durability system.

The durability analysis includes the purchase costs and installation of each item. The 40 year life cycle cost includes purchase, installation, annual maintenance, removal (water proof membrane), and periodic replacement costs for items such as sealers and membranes. Other items such as aggregate have a one time cost distributed over 40 years.

TABLE 1

LEVEL OF SERVICE (LOS) FOR STRUCTURAL DURABILITY IN PARKING STRUCTURES
SI Units

	ZONE I			ZONE III		
FLOORS:	LOS A	LOS B	LOS C	LOS A	LOS B	LOS C
Aggregate, low shrinkage type (1)	yes	yes	no	yes	yes	no
Air Entrainment (2)	4%	4%	4%	7%	7%	7%
Beam Depths (3)	L/20	L/24	L/26	L/20	L/20	L/24
Cathodic Protection (4)	no	no	no	no	no	no
Concrete Strength, MPa (5)	35	28	28	35	35	28
Conventionally Reinf. Slab Thickness (6)	L/28	L/36	L/40	L/28	L/32	L/40
Corrosion Inhibitor (7)	no	no	no	yes	yes	no
Dead Load Deflection (8)	L/600	L/480	L/360	L/600	L/600	L/480
Drainage (9)	yes	yes	yes	yes	yes	yes
Encapsulated PT Tendons (10)	yes	partial	partial	yes	yes	yes
Epoxy Coated Reinforcement (11)	no	no	no	yes	yes	no
Expansion Joint Spacing, m (12)	90	115	140	75	90	110
Increased Rebar Cover , mm(13)	25	25	28	50	40	40
Joint Sealants (13)	yes	no	no	yes	yes	yes
Lightweight Aggregate (14)	yes	yes	yes	no	no	yes
Min. Avg. Prestress, MPa, floors (15)	1.40	1.00	0.86	1.60	1.40	1.00
Min. Avg. Prestress, MPa, roof (15)	1.60	1.30	1.00	1.60	1.60	1.20
Post Tensioned Slab (16)	yes	yes	yes	yes	yes	yes
Precast Slab (16)	yes	yes	yes	yes	yes	yes
PT Slab Thickness (17)	L/40	L/44	L/48	L/36	L/40	L/44
Silica Fume (18)	no	no	no	yes	yes	no
Surface Sealers (19)	yes	no	no	yes	yes	yes
Temp. Tendons Avg. Prestress, MPa, floor (15)	0.86	0.86	0.70	1.00	0.86	0.86
Temp. Tendons Avg. Prestress, MPa, roof (15)	1.00	1.00	0.86	1.00	1.00	0.86
Water/Cement ratio (20)	0.40	0.50	0.55	0.40	0.40	0.45
Waterproof Membrane (21)	yes	no	no	yes	yes	no
Water Cured Concrete (16)	yes	no	no	yes	yes	no
Vibration Perception (22)	slight	distinct	strong	slight	distinct	strong

For notes, please see next page.

Footnotes for Tables 1

1. Always use the best aggregate available.
2. Always use at least 4%.
3. Consider in conjunction with dead load deflection and vibration.
4. Do not use with pre- or post-tensioned reinforcement [2].
5. Never use less than 4000 psi.
6. Conventionally reinforced (non-prestressed) slabs are not recommended in Zones II or III.
7. Corrosion inhibitors may contribute little if used with silica fume concrete or with precast concrete.
8. Consider in conjunction with beam and slab depths.
9. The first line of defense is good drainage.
10. Always use.
11. Never depend on epoxy coated reinforcement alone.
12. Consider independently of other durability measures [3,11,12].
13. Inexpensive protection [5].
14. Check long term shrinkage rate.
15. Always needed. Consider independently of other durability measures.
16. Always recommended.
17. Consider in conjunction with dead load deflection and vibration.
18. Not needed with precast concrete.
19. If used with silica fume concrete, only an initial coating needed.
20. Always preferred
21. Not normally needed, except over habitable areas.
22. Probably the most difficult item to deal with, because it is the most subjective [6].

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Floor Slab Durability Analysis

WALKER Parking Consultants/Engineers   Table 2
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Project: Example
Date: January 1995
City: San Francisco

This project has been designated for a mild climate, without ice and de-icing salts. The user should satisfy themselves that adequate safe guards are utilized in the selection of the criteria to protect the structure against premature deterioration.

FLOORS:	Selection	LOS	Initial Cost/sq. m	Life Cycle Cost/sq. m
Concrete				
Aggregate Type	Hardrock	A	$0.01	$0.00
Aggregate Shrinkage Rate	0.04	A	$0.01	$0.00
Air Entrainment Rate	4.00%	A	$0.01	$0.00
Corrosion Inhibitors	No	NR	$0.00	$0.00
Sealers, Penetrating Type	Yes	A	$0.06	$0.00
Silica Fume	No	NR	$0.00	$0.00
Strength at 28 days	35 MPa	A	$0.02	$0.00
Water/Cement Ratio	0.4	A	$0.03	$0.00
Water Cured Concrete	Yes	A	$0.00	$0.00
Reinforcing Steel				
Cathodic Protection	No	NR	$0.00	$0.00
Concrete Cover at Top	25 mm	A	$0.02	$0.00
Encapsulated PT System	Yes	A	$0.01	$0.00
Epoxy Coated Reinforcing Steel	No	NR	$0.00	$0.00
Min. Effective Prestress in Floor Slab	1.4 MPa	A	$0.01	$0.00
Min. Effective Prestress in Roof Slab	1.6 MPa	A	$0.01	$0.00
Temp. Min. Effective Prestress in Floor	0.86 MPa	A	$0.01	$0.00
Temp. Min. Effective Prestress in Roof	1 MPa	A	$0.01	$0.00
Structural Considerations				
Dead Load Deflection Ratio	L/600	A	$0.01	$0.00
Beam Span/Depth Ratio	L/20	A	$0.01	$0.00
Expansion Joint Spacing	76 m	A	$0.01	$0.00
Joint Sealers	YES	A	$0.00	$0.00
Lateral Load System	FRAME	A	$0.01	$0.00
Min. Slope on Floors	2.00%	A	$0.00	$0.00
Slab Span/Depth Ratio	L/43	B	$0.01	$0.00
Vibration Perception	SLIGHT			
Waterproof Membrane on Floors	NO	C	$0.00	$0.00
THIS SELECTION HAS A DURABILITY RATING OF		**A**	**$0.23**	**$0.01**