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ERRORS IN CONCRETE STRUCTURES

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NOTES

Errors in concrete structures

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One hundred and eighty-eight cases of error in concrete structures, 29 of which resulted in collapse and 118 in distress, deterioration, excessive cracking, spalling, deflection, or settlement, were collected from consulting engineers and government departments across Canada. The survey indicated that about half the errors originated in the design and the other half were due to faulty construction. Most of the collapses occurred during construction, mainly as a result of inadequate formwork or temporary bracing; some were due to detailing errors in design. Most serviceability failures, on the other hand, occurred during use. Many of those failures were due to lack of consideration in design of deflection or of the effects of temperature, shrinkage, and creep.

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Survey

A survey of errors that led to or could have led to failure of concrete structures was carried out by sending a questionnaire to design engineers and inspection agencies across Canada. The survey was undertaken as part of a larger one across North America organized by Committee 348 of the American Concrete Institute (ACI) in an attempt to "develop a profile of the practices, activities and circumstances making up the design and construction of concrete structures that tend to lead to-errors." Details of the questionnaire are given in Allen (1977). Anonymity of names and places concerning each case was assured as this information was not requested.

In Canada the questionnaire was sent to approximately 250 consulting engineering firms, to all federal and provincial government departments of highways, public works, and agriculture, and to building departments of municipalities with a population of more than 100 000. The responses from various sources are given in Table 1. The 188 cases reported were obtained from about 50 sources ranging from 1 to 22 cases each.

The responses varied from detailed and illuminating to vague and occasionally ambiguous. To a considerable extent this was due to the lack of clarity in the questionnaire (Allen 1977). For example, "distress" was not clearly defined and in analyzing the results was interpreted as a structural condition that indicated insufficient safety against collapse, not just unserviceability. Despite this shortcoming, a summary of the results will be of interest to designers and builders. A more detailed analysis of the results of the ACI error survey is given in Fraczek (1979).

Discussion of Results

Tables 2 and 3 provide a breakdown of errors reported according to type of construction and component. Because of the fairly broad coverage indicated in Tables 1, 2, and 3, the cases provide a sample that is fairly representative of the total population of failures of engineered concrete structures in Canada, except for those caused by deterioration that occur after many years and may not be considered as structural failures. The cases do not provide a representative sample of the total

TABLE 1. Responses

Consulting engineers (a few from testing labs.)	142
Municipal building departments	13
Provincial highway departments	16
Government public works and hydro departments	12
Government agricultural departments	5
Total	188

TABLE 2. Type of construction

Cast-in-place construction	
Reinforced concrete	135
Posttensioned concrete	16
Composite construction	6
Plain concrete	2
Concrete block	7
Precast construction	
Reinforced concrete	8
Prestressed concrete	14

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TABLE 3. Component affected

Slab	41
Bridge deck	10
Beam	23
Column	10
Pile or pier	16
Wall	8
Retaining, tank, or basement wall	25
Foundation	13
Connection	28
Formwork, temporary bracing or fastening	12

TABLE 4. Types of errors

	No. of cases
Design—total	103
Loading (including temperature and shrinkage)	22
Analysis and design	60
Detailing	25
Construction—total	92
Formwork, bracing, supports	27
Installation of reinforcing	31
Concreting	21
Overloading or impact	8
Contractor's interpretation of working drawings	10
Use—overloading	1

population of errors because most errors caught in time were not reported.

Table 4 gives a breakdown of the types of errors reported. Approximately half were design errors and half were construction errors. Most design errors were classified as "analysis and (or) design" or "calculation" in the questionnaire but a number of these were probably "detailing" errors, i.e., inadequate consideration of connections, anchorages, and reinforcing details. A number of detailing errors, some of which led to collapse, were caused by a lack of consideration of the effects of temperature or shrinkage or of eccentric forces.

Table 5 gives a more detailed breakdown of those errors that resulted in failure. Most collapses occurred during construction, primarily due to formwork failure or inadequate temporary bracing. A number of collapses occurred because of detailing error in design. Of the six collapses that occurred during use, two were due to detailing error and two to not considering lateral load. Most serviceability failures, i.e., excessive cracking and deflection, occurred during use and originated primarily in the design. Deflection problems most often arose because of inadequate consideration of deflection or of the effects of deflection. Only seven cases of deterioration were reported, which is certainly not representative of how widespread it is in practice.

More detailed descriptions of the errors given in the responses are contained in Table 6. These are self-explanatory and are worth studying to understand the kinds of troubles that arise in concrete structures in Canada. Table 6 indicates that most design errors resulting in structural failure (including failure of temporary supports), other than those due to deterioration, were due to a misconception or forgetting of the general behaviour of the structure as a whole, or of its members, connections, or details, and of the kinds of forces that will occur. Relatively few were due to an inaccurate assessment of the magnitudes of forces or resistances that occurred or of the safety factor required. Table 6 indicates that contruction errors other than design of temporary supports consisted primarily of incorrect procedure, for example, omissions, misplacement, wrong materials or products, incorrect curing.

TABLE 5. Breakdown of cases where failure occurred

	Failure occurred during		Due to errors in				
			Design		Construction		Use
	Use	Construction	Detailing	Other	Formwork bracing etc.	Other	
Ultimate limit states							
Collapse	6	23	6	6	13	6	
Distress	32	26	12	19	7	25	1
Serviceability limit states							
Cracking, spalling	17	8	6	12	1	7	
Deflection, settlement	17	11	1	16	1	11	
Clearance, gaps, holes	2	1		2	1		
Deterioration	6	1		3		4	
Total	80	70	25	58	23	53	1

TABLE 6. Descriptions of errors

Error description	No. of cases
1. Design	
Detailing error—collapse	7
Lateral loading not properly considered	8
Lateral support not properly considered	3
Neglect of temperature, shrinkage, or creep effects	10
Inadequate soil investigation	7
Hydrostatic uplift or soil swelling	2
Neglect of deflection effects	8
Plain concrete or block walls subject to earth pressure	4
Concrete specification (no air entrainment, sulphate attack)	2
Leakage protection	1
Overlooked weight of masonry wall	1
Avalanche forces greater than predicted	1
Lack of overflow device—hydrostatic tank pressure	1
Neglected radial temperature movements in curved bridge (cracked pier)	1
Neglected tension across tapered pier	1
Skew reinforcing—corner cracking of bridge deck	1
No inside reinforcing in cylindrical shear wall—leakage	1
Eccentric loading neglected by precaster	1
No stirrups	1
Sharp curves in prestress splice detail—cracking	1
Unstable hangar supports for T beams	1
Detailing—bar congestion	1
Panels bowed out at corner of building—leakage	1
Insufficient bridge clearance	1
Detailing to avoid effects of ice formation	1
2. Construction	
Formwork failure—collapse	6
Thawing of ground below mudsills—collapse	2
Inadequate temporary bracing—collapse	5
Overloading during construction	6
Impact during construction	5
Concrete mix	6
Frozen concrete	2
Inadequate chair supports for reinforcing	3
Wrong steel	2
Settlement or sliding due to improper construction methods	7

TABLE 6 (*Concluded*)

Error description	No. of cases
Posttensioning anchor stirrups left out	2
Concrete insufficiently strong during posttensioning	1
Unbalanced construction loads—wharf caisson cracked	1
Sliding bearing concreted in	1
Wooden pegs left in concrete—leakage in waffle slab	1
Mud in pier shaft	1
Wall form 1/3 required thickness	1
Block wall form not braced against concrete pressure	1
Old concrete surface not cleaned—crack due to bond failure	1
Reinforcing placed upside down	1
Overexcavation of ground intended to resist sliding	1
Frost penetration below footing reduced soil strength	1
Contractor substituted bearing materials—corrosion	1
Flying forms not anchored—flew off	1
Inadequate temporary fastening of precast panel	1
No erection bracing between box girders	1
Protection against ice formation in holes	1
3. Other	
Overloading during use	1
Soil erosion due to watermain leak	1

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ALLEN, D. E. 1977. ACI error survey—Canadian data. Division of Building Research, National Research Council of Canada, Ottawa, Ont., Building Research Note No. 123.

FRACZEK, J. 1979. ACI error survey. Concrete International. (To be published.)