

by one of the steel-wheel rollers. All free edges were cut back to expose a dense vertical edge.

Density and percentage payment for each lot are given below (1 Mg = 1.1 tons):

Lot	Megagrams Placed	Average Mat Density	Average Joint Density	Payment (%)
1	547	98.5	—	100
2	1120	97.9	96.1	95.5
3	494	97.7	96.9	97.0
4	1280	97.9	95.2	91.0
5	318	96.1	94.1	81.0
6	708	98.4	97.4	100
7	1498	98.4	97.2	100
8	1362	98.4	97.2	100
9	600	98.3	98.0	100
10	1450	98.3	95.5	93.5
11	1590	98.6	97.4	100
12	1797	99.1	97.7	100
13	1325	98.3	97.3	100
14	1000	97.7	96.6	97.0

Average and standard deviation values for the entire job for aggregate gradation, asphalt content, and density are given below:

Item	Shemya		Previous Jobs	
	Average	Standard Deviation	Average	Standard Deviation
Density, %				
Mat	98.2	1.07	97.8	1.0
Joint	96.7	1.43	96.8	1.5
Asphalt content, %	6.7	0.33	—	0.20
Gradation, % passing sieve size				
12.7 mm (½ in)	100	0	95 to 100	2.0

Item	Shemya		Previous Jobs	
	Average	Standard Deviation	Average	Standard Deviation
9.52 mm (¾ in)	96.8	1.2	95 to 100	2.0
4.76 mm (No. 4)	72.2	2.1	30 to 95	2.5
2.38 mm (No. 8)	51.7	1.4	30 to 95	2.5
0.047 mm (No. 16)	38.3	1.2	30 to 95	2.5
0.023 mm (No. 30)	28.4	1.5	20 to 30	2.0
0.297 mm (No. 50)	16.7	1.2	10 to 20	1.5
0.149 mm (No. 100)	9.4	1.3	0 to 10	1.0
0.074 mm (No. 200)	6.9	1.0	0 to 10	1.0

Most of the data obtained from the Shemya job compared reasonably well with data obtained on previous jobs. Given the satisfactory material and construction properties obtained on this job under poor weather conditions, it is believed that density and other quality parameters can be better controlled and evaluated by using statistical rather than conventional specifications.

REFERENCES

1. T. F. McMahon and others. *Quality Assurance in Highway Construction*. U.S. Department of Transportation, 1969.
2. U.S. Bureau of Public Roads. *Proc., Statistical Quality Assurance Workshop*, Oct. 22 to 24, 1968, Washington, D.C.
3. E. R. Brown. *Statistical Quality Control Procedures for Airport Pavement Materials*. U.S. Department of Transportation, Rept. FAA-RD-73-199, Oct. 1975.

Publication of this paper sponsored by Committee on Quality Assurance and Acceptance Procedures.

Quality Assurance in Bridge Construction in Canada: A Study of Inspection and Testing Programs

J. Ryell and L. Bowering, Ontario Ministry of Transportation and Communications

A study is summarized of inspection times and concrete testing programs on 21 contracts of the Ontario Ministry of Transportation and Communications containing 41 bridges built in 1974. The study assessed the degree of uniformity in the Ministry's work with respect to inspection and field testing programs and compares such programs, where appropriate, with recommended practices and specification requirements. Data are presented on inspection times for reinforcing steel, formwork and falsework, concrete placement, erection of beams, stressing and grouting of cables, deck waterproofing, and other operations. Test programs on fresh and hardened concrete are discussed. The study notes a wide variation in the effect of inspection on comparable segments of different structures and attributes this partly to the individual inspector's perception of the scope and nature of the required inspection effort. A practical bridge-inspection manual and checklists that will establish uniform standards of inspection and provide the basis to build more accountability into inspection work are required. It is concluded that inspection and testing programs, particularly on critical segments of the bridge structure such as the deck, require substantial improvement.

In 1974, a project was carried out by the Ontario Ministry of Transportation and Communications (MTC) to evaluate the adequacy of current MTC quality control of bridge construction, particularly of bridge-deck construction. One part of the project and the subject of this report consisted of a study of current inspection and testing programs by means of data collection from 21 active contracts. The 41 structures contained in these contracts included a number of design types and were distributed in each of the five regions of the province of Ontario.

The purpose of the study was to assess the degree of uniformity that exists throughout the province with respect to inspection and field testing programs and to compare such programs, where appropriate, with recommended practices and specification requirements. The data collection was carried out on all MTC con-

tracts that contained active structural work for the period September 1 to December 13, 1974.

Tests on slump, air content, temperature, and compressive strength of concrete were summarized from the concrete construction report filled out daily by the inspector and from the report on concrete strengths issued by the testing laboratory. Compliance was based on the

requirements of MTC specifications in effect at the time of the study and on the contract drawings. The adequacy of the number and frequency of field tests was judged by comparison with the table contained on the back of the inspector's concrete construction report (Figure 1), which is formulated in customary rather than SI units of measurement.

Figure 1. Form for field testing of concrete from inspector's concrete construction report.

LEGEND: < = LESS THAN > = GREATER THAN		TESTING OF CONCRETE (1) - NUMBERS AND FREQUENCY OF FIELD TESTS												LABORATORY SERVICES OFFICE	
LOCATION	STRUCTURES						PAVEMENTS & BASE (Exposed Concrete (7))			CURB & GUTTER (Exp. Concrete (7))		CULVERTS & MISC. WORK		PLANT MADE PRECAST BEAMS, PILES, ETC. (8)	
	FOUNDATIONS, WALLS, PIERS, COLUMNS, ABUTMENTS			DECK SLABS, APPROACH SLABS, BRIDGE CURBS & SIDEWALKS (Exposed Concrete (7))											
SPECIFIED 28 DAY COMPRESSIVE STRENGTH OF CONCRETE P.S.I.	2,500, 3,000 4,000 & 5,000 (11)			3,000, 4,000 & 5,000 (11)			3,000 & 3,500			3,000		3,000		4,000 AND GREATER	
QUANTITY OF CONCRETE PLACED PER DAY CUBIC YARDS (2)	< 100	100 TO 500	> 500	< 100	100 TO 500	> 500	< 500	500 TO 1,000	> 1,000	< 100	> 100	< 100	> 100		
TESTS	AS DIRECTED BY THE ENGINEER, TO BE RELATED TO THE NUMBER OF UNITS CAST, AND THE QUANTITY OF CONCRETE PLACED, PER DAY														
28-DAY CYLINDERS (3) (4) (10)	1 SET PER DAY (6)	2 SETS PER DAY	3 SETS PER DAY	2 SETS PER DAY (6)	3 SETS PER DAY	4 SETS PER DAY	1 SET PER DAY (6)	2 SETS PER DAY	3 SETS PER DAY	1 SET PER DAY (6)	2 SETS PER DAY	1 SET PER DAY (6)	2 SETS PER DAY		
10-DAY FLEXURAL BEAMS (3) (5) (10)	—	—	—	—	—	—	1 BEAM PER DAY	2 BEAMS PER DAY	3 BEAMS PER DAY	—	—	—	—	—	
AIR TEST (7)															
READY-MIX AND CENTRAL-MIX PLANT	AFTER SATISFACTORY CONTROL (9) IS ESTAB- LISHED 1 TEST FOR EACH 5 TRUCKLOADS OF CON- CRETE			1 TEST FOR EACH TRUCK- LOAD OF CONCRETE WHEN RATE OF PLACE- MENT IS 50 CU. YDS. PER HOUR OR LESS, WHEN RATE OF PLACEMENT EXCEEDS 50 CU. YDS. PER HOUR AND AFTER SATISFACTORY CONTROL (9) IS ESTABLISHED. 1 TEST FOR EACH 3 TRUCK- LOADS OF CONCRETE.			AFTER SATISFACTORY CONTROL (9) IS ESTAB- LISHED 1 TEST FOR EACH 3 TRUCKLOADS OF CON- CRETE.			1 TEST FOR EACH TRUCK- LOAD OF CONCRETE.		AFTER SATIS- FACTORY CON- TROL (9) IS ESTABLISHED 1 TEST FOR EACH 5 TRUCKLOADS OF CONCRETE.		AFTER SATISFACTORY CONTROL (9) IS ESTABLISHED 1 TEST FOR EACH 5 TRUCK LOADS OF CONCRETE	
SITE-MIX	AFTER SATISFACTORY CONTROL (9) IS ESTABLISHED 1 TEST FOR EACH 10 TO 25 CUBIC YARDS CONCRETE DEPENDING ON SIZE OF MIXER ETC.														
SLUMP TEST	1. AT THE BEGINNING OF A CONCRETE PLACEMENT OPERATION AND AT SUBSEQUENT INTERVALS TO INSURE THAT THE SPECIFICATION REQUIREMENTS ARE MET. 2. WHENEVER CYLINDERS OR FLEXURAL BEAMS ARE MADE.														
YIELD	1. WHENEVER THE YIELD OF A CONCRETE MIX IS CHALLENGED. 2. TWICE PER DAY ON CONCRETE PAVEMENT OR CONCRETE BASE. 3. WHENEVER MATERIALS OR MIX PROPORTIONS ARE CHANGED.														
TEMPERATURE	1. IN HOT OR COLD WEATHER CONDITIONS, AT FREQUENT INTERVALS UNTIL SATISFACTORY CONTROL (9) IS ESTABLISHED. 2. WHENEVER CYLINDERS OR FLEXURAL BEAMS ARE MADE.														
ACCELERATED STRENGTH TESTING (3)	AS SPECIFIED IN MEMORANDUM OB-C-69-5 DATED OCT. 8, 1969, 'ACCELERATED STRENGTH TESTING'.														
NOTES:															
(1) THE NUMBER AND FREQUENCY OF THE TESTS INDICATED REPRESENTS A REASONABLE LEVEL OF TESTING FOR CONCRETE ORIGINATING FROM PLANTS WITH A GOOD STANDARD OF QUALITY CONTROL. THE FREQUENCY OF TESTING SHOULD BE INCREASED FOR CONCRETE PRODUCED BY PLANTS WITH LOWER STANDARDS OF CONTROL.															
(2) THE CONCRETE QUANTITIES SHOWN REFER TO ALL CONCRETE OF THE SAME CLASS, WITH THE SAME MIX SERIAL NUMBER, ORIGINATING FROM THE SAME CONCRETE PLANT FOR THE SAME CONTRACT. WHERE MORE THAN ONE MAJOR CONCRETE PLACEMENT OPERATION OCCURS ON THE SAME CONTRACT DURING THE SAME DAY E.G., THE CONSTRUCTION OF A SECOND BRIDGE DECK, EACH OPERATION SHALL BE TESTED AT THE FREQUENCY SHOWN.															
(3) 28 DAY CYLINDERS AND 10 DAY FLEXURAL BEAMS ARE TO BE MADE AT THE FREQUENCY SHOWN TO DETERMINE WHETHER THE CONCRETE MEETS THE REQUIREMENTS OF THE STRENGTH SPECIFICATION. IN ADDITION JOB CURED CYLINDERS AND FLEXURAL BEAMS WILL FREQUENTLY BE REQUIRED BY THE ENGINEER TO DETERMINE CONCRETE STRENGTH FOR THE PURPOSE OF FORM REMOVAL, STRESSING, OPENING TO TRAFFIC ETC. 28 DAY STANDARD CURED COMPRESSIVE STRENGTH RESULTS CAN BE PREDICTED WITH REASONABLE ACCURACY USING THE AUTOGENOUS CURED ACCELERATED TEST PROCEDURE.															
(4) A COMPRESSIVE STRENGTH TEST IS THE AVERAGE STRENGTH OF TWO STANDARD 6 IN. x 12 IN. CYLINDERS.															
(5) A FLEXURAL BEAM TEST IS THE AVERAGE STRENGTH OF TWO BREAKS IN A STANDARD 6 IN. x 6 IN. x 36 IN. BEAM.															
(6) IN VERY SMALL VOLUME PLACEMENT OPERATIONS, CYLINDERS NEED NOT BE MADE EACH DAY.															
(7) EXPOSED CONCRETE* MUST BE PROPERLY AIR ENTRAINED AND SUFFICIENT TESTING CARRIED OUT TO ENSURE THAT THIS IS ACHIEVED. ON MANY CONCRETE PLACEMENT OPERATIONS, PARTICULARLY WHERE THE PROCEDURE IS KNOWN TO HAVE LESS THAN EXCELLENT STANDARDS OF CONTROL IT IS NECESSARY AND POSSIBLE TO CHECK EACH LOAD OF CONCRETE FOR AIR CONTENT. ON WORK SUCH AS PAVEMENTS AND LARGE BRIDGE DECKS WHERE VERY RAPID RATES OF CONCRETE PLACEMENT OCCUR, I.E., > 50 CUBIC YARDS PER HOUR, IT IS UNPRACTICAL TO CONTINUE SUCH A FREQUENCY OF TESTING FOR VERY LONG. UNDER SUCH CONDITIONS AND ONCE SATISFACTORY CONTROL HAS BEEN ESTABLISHED, THE FREQUENCY OF TESTING CAN BE REDUCED FOR AS LONG AS EACH TEST RESULT FALLS WITHIN SPECIFICATION REQUIREMENTS. WHEN A TEST RESULT FALLS OUTSIDE THE SPECIFIED LIMITS THE TESTING FREQUENCY SHOULD REVERT TO ONE TEST PER LOAD OF CONCRETE UNTIL SATISFACTORY CONTROL IS RE-ESTABLISHED.															
(8) QUALITY CONTROL TESTING SHALL BE CARRIED OUT BY CONTRACTOR AND SUPERVISED BY M.T.C.															
(9) SATISFACTORY CONTROL IS CONSIDERED TO HAVE BEEN ESTABLISHED WHEN TESTS ON FIVE CONSECUTIVE TRUCKLOADS OR BATCHES (SEE NOTE (2)) OF CONCRETE ARE WITHIN SPECIFICATION REQUIREMENTS.															
(10) SEE ATTACHED SHEET 'METHOD OF RANDOM SELECTION OF CONCRETE SAMPLE ETC															
(11) THE ENGINEER MAY DIRECT THAT THE FREQUENCY OF TESTING FOR 5,000 P.S.I. CONCRETE BE INCREASED ON SOME OCCASIONS.															
* CONCRETE SUBJECTED TO FREEZE-THAW CONDITIONS WITH DE-ICING SALTS PRESENT E.G., BRIDGE DECKS, PAVEMENTS, CURB AND GUTTER SECTIONS WALLS AND COLUMNS AFFECTED BY ROAD SPLASH.															

Figure 2. Daily report on bridge inspection.

DAILY REPORT ON BRIDGE INSPECTION																																
DISTRICT NUMBER <u>6</u>	CONTRACT NUMBER <u>74-20</u>																															
SITE NUMBER <u>131-74</u>	DATE <u>July 16, 1974</u>																															
INSPECTOR'S NAME <u>T. L. Brown</u>	CLASSIFICATION <u>H. 1. A. 3</u>																															
INSPECTION RECORD <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 30%;">*FUNCTION</th> <th style="width: 30%;">*LOCATION</th> <th style="width: 40%;">TIME (Hrs)</th> </tr> </thead> <tbody> <tr><td>2</td><td>A-North</td><td>3.50</td></tr> <tr><td>1</td><td>B-#1</td><td>1.</td></tr> <tr><td>15</td><td></td><td>0.50</td></tr> <tr><td>17</td><td></td><td>3.00</td></tr> <tr><td> </td><td> </td><td> </td></tr> <tr><td> </td><td> </td><td> </td></tr> </tbody> </table>			*FUNCTION	*LOCATION	TIME (Hrs)	2	A-North	3.50	1	B-#1	1.	15		0.50	17		3.00															
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<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> FUNCTION CODE 1/ Check excavation. 2/ Check reinforcing steel placement. 3/ Inspect concrete placement. 4/ Perform quality control tests on concrete. 5/ Inspect formwork. 6/ Inspect falsework. 7/ Check bearing placement. 8/ Check stressing cable placement. 9/ Inspect stressing operation. 10/ Inspect grouting operation. </div> <div style="width: 45%;"> 11/ Inspect beam erection. 12/ Inspect waterproofing operation. 13/ Inspect paving operation. 14/ Inspect pile-driving operation. 15/ Instruct contractor's staff. 16/ Compile diary and inspectional forms. 17/ Visits to the concrete plant and other suppliers. 18/ Other 19/ 20/ </div> <div style="width: 45%;"> LOCATION CODE A/ Abutment Footings. B/ Pier Footings. C/ Abutments. D/ Piers. E/ Wingwalls. F/ Deck. G/ Ballast Walls. H/ Curbs. J/ Parapet Walls. </div> </div>																																

METHOD OF COMPILING THE DAILY REPORT ON BRIDGE INSPECTION

1/ Every day that the contractor works, each bridge inspector completes one form for each bridge inspected. (It is possible that some forms will indicate no inspection for a particular day. This may be due to the fact that construction activity is suspended because of delays or inclement weather. Also, forms will indicate no inspection when the Inspector is not physically on-site).

2/ Record the bridge location information, the date, your name and classification.

3/ In the Inspection Record section, under the function column, insert the code number that describes the work you are performing. If your work does not fit into one of the categories listed on the reverse side of the form, insert one of the unassigned numbers and write a brief description of your work on the reverse side of the form, beside the number you have selected. Code number 18, designated as Other, will include time spent on phases of the contract other than the bridge, time spent on administration - e.g. time sheets, coffee breaks, travel time, etc. We are not interested in a breakdown of this time.

4/ Under the Location column, insert the code letter that indicates the section of the bridge you are inspecting. Beside the code letter, designate which abutment, pier, etc. if there is more than one. For example, write N for north abutment and No. 1 for pier number one.

5/ Record your time to the nearest half hour.

6/ In the Record of Visits to Bridge Site section, record the name, section and position title of all individuals that visit the site. Since other district inspectional staff will be compiling their own form, their visits will not be recorded in this section.

7/ Record the duration of all visits to the nearest half hour.

8/ Under the Reason column, briefly state the problem that precipitated the visit. An unsolicited visit will be referred to as a general inspection.

9/ Enquiries regarding the form may be directed to: L. Bowring at 248-3965 or 248-3966.

Inspection time was summarized by using the daily report on bridge inspection form shown in Figure 2. All bridge inspectors completed one report for each day that the contractor worked. This form recorded the hours spent on each inspection function—steel placement, stressing operation, pile driving, and so on—for each segment of the structure as well as all noninspection time. Visits to the site by personnel from the regional, head, and district offices were also recorded on this form.

A strict comparison between the inspection effort actually made and what is required is not possible: No formal standards exist within the MTC for inspection duties on modern bridge construction. Some guidance on various facets of inspection is contained in documents such as MTC inspection and construction manuals, miscellaneous technical notes distributed at training courses, and memorandums originating from the Operations Division.

The project supervisor for research and development visited each contract site at least once during the early part of the project to outline the purpose and the aims of the study, to promote interest in the program, and to

ensure that the daily report on bridge inspection was being correctly filled out by each inspector.

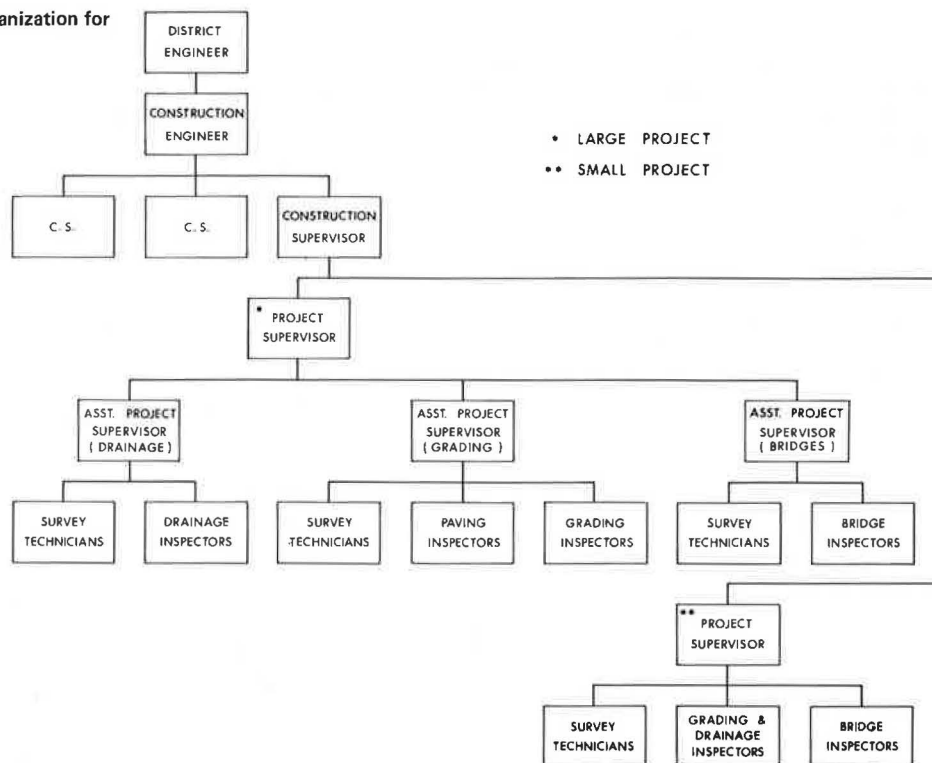
MTC DISTRICT STRUCTURE

At the time of the study, administration of construction contracts was the responsibility of 18 district offices spread over the 1 068 588 km² (412 582 miles²) of Ontario. The organizational structure of these offices is shown in Figure 3. In most cases, only the district engineer and the construction engineer were professional engineers.

In addition to district offices there are five regional offices in Ontario that provide technical assistance and advice in matters of construction and quality assurance. Each region typically has (a) a quality control engineer who is assisted by several specialized supervising inspectors and (b) a fully equipped materials testing laboratory.

The head office of MTC in Toronto also provides various technical services to the district engineer's staff. The more important head-office functions in relation to the quality assurance system are represented

Figure 3. MTC district-level organization for construction.



by a structures office that is responsible for a specialized technical service such as cable stressing and approval of falsework plans; a quality control office that is concerned with technical advice on materials technology, inspection, and testing; and a laboratory services office that carries out concrete mix designs and testing and approval of products and materials.

TYPES OF BRIDGE DECKS

In this study, bridge decks are considered in two categories:

1. Thin-slab decks are single-course, reinforced concrete slabs supported on steel or precast concrete beams. In most cases the slab thickness is 19 cm (7.5 in) and contains four layers of reinforcing steel. The layout of formwork and reinforcing steel for such decks is relatively straightforward.
2. Thick-slab decks are reinforced concrete slabs posttensioned in a longitudinal and transverse direction. In most cases the slabs contain voids to reduce dead weight. When round metal voids are used, the concrete slab is placed in a single operation. When wooden, rectangular void forms are used, the concrete is placed in two operations. The overall slab depth for most structures in this group varies from 0.6 to 1.5 m (2 to 5 ft).

The layout of voids, reinforcing steel, and stressing cables in thick-slab decks is complex and congested, particularly around cable anchorages and above support columns.

All bridge decks were waterproofed and paved with bituminous materials.

DETAILS OF THE STUDY

In analyzing the data it is important to recognize the inherent limitations of the study and their effect on the conclusions.

The short data collection period resulted in only partial coverage of the construction of the structures. In some cases the various segments of a structure are not entirely covered; e.g., a portion of the substructure—a column or an abutment—was completed prior to the study or was not constructed during the study period. If a particularly complex or relatively simple portion were completed during the study but not the remainder of the structure, a false impression of the effectiveness of the inspection may be derived.

Having the inspectors record and report their own daily tasks may have an inflationary effect on inspection time. The knowledge that one's performance is under observation will generally produce an increased effort. In addition, actual inspection time may be "padded" to indicate superior performance or to hide portions of the working day when inspection activity is not required. To minimize these factors, it was requested that the forms be sent directly to the project supervisor for research and development. This procedure eliminated scrutiny of forms by field or district office supervisors and any influence this would have on the results.

Some idea of the overall effectiveness of the inspection effort can be gained by reviewing the inspection time spent on various phases of bridge construction. Several factors contribute to the ratio between the time spent and the inspection accomplished. The ability and the experience of the inspector are probably the most important factors. A fully experienced, capable inspector will achieve the objectives in a minimum of time. An inept inspector will not produce the desired results regardless of the time spent.

Staffing is also a factor. Overstaffing or understaffing of a contract will result in a corresponding variance in the inspection time for each operation. The influence this situation would have on the quality of inspection cannot be determined from this study, but a reasonable assumption would be that understaffing would result in a decline in the quality of inspection and overstaffing would have little if any effect.

Many inspection and testing operations are directly related to the contractor's speed and ability. When a contractor is capable and desires to produce a quality product, the inspector need only check the finished product for adherence to tolerances and specifications. If the contractor lacks experience or attempts to cut corners, some operations may have to be performed a second time so that the inspector can demonstrate the proper procedure. In this case, the inspector may have to observe the entire operation, solving problems and correcting errors as they occur.

Inspection times related to a specific structure or part of a structure can thus be expected to vary widely across the province, but such variation will usually not indicate unsatisfactory work by either the contractor or the MTC staff.

Testing programs can also be expected to vary between contracts but to vary much less than inspection times. The number and the frequency of field tests of concrete required by the MTC were developed over many years of bridge-construction experience and appear rational when they are compared with the requirements of other authorities and established national and international standards. Situations are not likely to arise in which the number and frequency of tests should be much less than those called for in the concrete construction report, but the nature of the contractor's operation may often require an increased frequency of testing.

Analysis of the daily report on bridge inspection for all bridge sites indicates that 60 percent of the inspector's time is spent in the field on inspection and testing duties, 7 percent in the office compiling diaries and records and studying contract documents, and 33 percent on work other than inspection and testing, off-site visits to concrete plants, vacations and sick leave, and nonproductive time attributable to inclement weather or lack of work.

Inspection and Testing

Placement of Reinforcing Steel

Establishing the time required to properly inspect the placement of a megagram of reinforcing steel is difficult. Variables that affect inspection time include (a) the complexity of the reinforcing steel configuration, (b) the skill of the contractor's staff, (c) the ability of the inspector, and (d) the inspector's concept of the inspection procedures. From the range of inspection times shown in Figures 4, 5, and 6, it is evident that these variables have considerable influence. Among these variables, the inspector's view of the scope and nature of the inspection effort is probably largely responsible for any wide variation. Some inspectors act as foremen, instructing the contractor's staff at the site during the entire operation. Others check the steel after the contractor has placed it and then advise the contractor of deficiencies.

Checking the steel for a typical three-span, thin-slab bridge deck in this study represents an average inspection time of almost 2 d. This at least indicates that on MTC contracts, as they are presently staffed, adequate inspection time is available and is utilized as the basis for a reasonable inspection effort.

The longer times and greater variability of inspections of reinforcement in the substructure appear to be predictable; such work is often more complex and more difficult to inspect because of restricted access, and contains relatively small quantities of steel. In contrast, some bridge decks contain large quantities of reinforcement but normally require less inspection

time because of the standard size and spacing of reinforcing bars.

The main improvements in reinforcement inspection that seem to be required are (a) establishment within the MTC of uniform standards covering the scope of the inspection effort, (b) providing the inspector with clearer placement drawings, and (c) avoiding situations in which the inspector supervises steel placement on behalf of the main contractor.

Concrete Placed in the Deck

Originally, inspection and testing of concrete were to be recorded as two operations, but the inspectors often experienced difficulty in separating the time and reported the total time under one heading. In the interest of uniformity, therefore, these two operations have been combined for reporting purposes. Figure 7 summarizes the inspection and testing time on 14 deck pours. As may be expected, the time spent on inspection and testing varies widely; it averages 8.6 h/100 m³ (131 yd³) of concrete for the 10 thin-slab decks and 5.2 h for the 4 thick-slab decks.

Establishing an optimum inspection time for a typical bridge deck is difficult because of major differences in such factors as structural complexity, concrete placement rate, and contractor's operation. Generally, however, the program of concrete testing required for a bridge deck and the need for continuous inspection of the placing, consolidating, and finishing operations call for at least three inspectors for the duration of the concreting operation.

The required inspection and testing time for 191 m³ (250 yd³) of concrete placed over 8 h in a thin-slab deck would be 12.6 h/100 m³ (131 yd³) of concrete; for 535 m³ (700 yd³) of concrete placed over 10 h in a thick-slab deck, an inspection time of 5.6 h/100 m³ of concrete would be required. This amount of inspection and testing time was not put into the majority of deck slabs for which data are available; in some cases the time that was spent appears to have been inadequate. It is possible in the more extreme cases that unreported help was given by survey technicians and other MTC staff. But, because each contract was asked to report all inspection time, it must be assumed that a reasonable inspection effort was not made on many of the deck slabs studied. Shortage of inspection staff may be partly responsible for this underinspection.

Cylinder Tests

The requirements contained in the concrete construction report for the making and testing of 28-d cylinders are related to the size of the concrete placement operation and allow little latitude in number and frequency of tests. It is recognized that 34-MPa (5000-lbf/in²) concrete may require an increased amount of testing at the discretion of the engineer, but no advice is given on the number of specimens to be made for very large concreting operations, i.e., those in excess of 765 m³ (1000 yd³). Table 1 gives concrete compressive strength data for 14 study sites.

In total, 80 sets of 28-d cylinders representing 5757 m³ (7529 yd³) of deck concrete were made or 1 set for each 72 m³ (94 yd³). Approximately half of the bridge decks were represented by adequate cylinder testing programs. There was a tendency to make more cylinders than were asked for on 34-MPa (5000-lbf/in²) concrete and fewer than were specified on most 28-MPa (4000-lbf/in²) deck slabs. On one thin-slab deck only 1 set was made for 253 m³ (331 yd³) of concrete, which is clearly inadequate.

Seventy percent of the total sets of cylinders, or 186 sets, were tested at ages other than 28 d; this apparently reflects a demand for data on the early strength of concrete for purposes of stressing and falsework removal. Fabrication and testing of such cylinders are very expensive processes. Because the data are usually needed

Figure 4. Inspection time on placement of reinforcing steel: bridge decks.

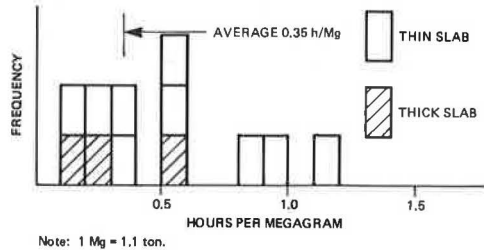


Figure 5. Inspection time on placement of reinforcing steel: footings.

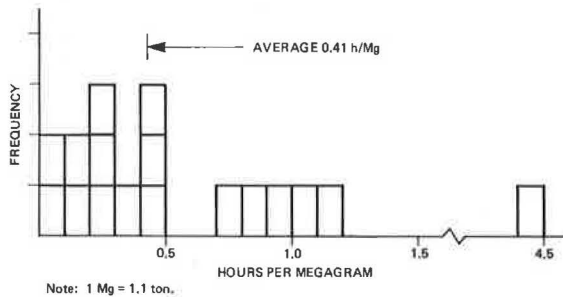
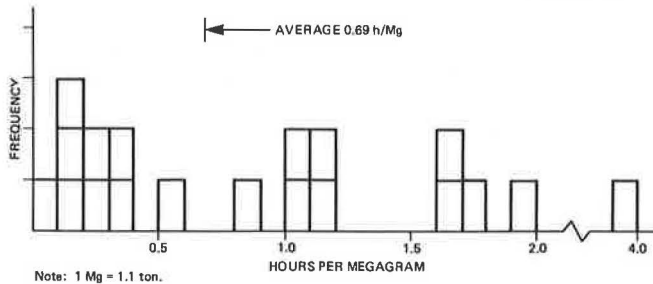


Figure 6. Inspection time on placement of reinforcing steel: substructure.



by the contractor before the next step in construction can proceed, it seems logical that the cost of such testing should be borne by the contractor. This study did not indicate that the approved concrete suppliers were carrying out the program of quality control testing required in MTC specifications.

The basic 28-d cylinder strength requirement—that at least 90 percent of tests must meet or exceed the minimum specified strength—was complied with on the 10 deck slabs in which 28-MPa (4000-lbf/in²) concrete was used. The fact that no cylinder test fell below the minimum strength indicates the relative ease of attaining specified strength levels for this class of concrete. This was not the case for 34-MPa (5000-lbf/in²) concrete. Two 34-MPa deck slabs met the specified strength requirements, but two fell far short. The two failures occurred at two sites that were included in one contract; 62 and 29 percent of the tests fell below 34 MPa. A detailed review of the 28-d tests for site 5-219 at which 62 percent failures occurred (Table 1) indicates that almost half of the tests exceeding 34 MPa had slump values and air contents far below the average for the total number of tests reported. In all probability, a high percentage of the concrete in this deck did not meet specification requirements.

Although the results of the strength tests on these two decks were not satisfactory, it should be noted that an impressive amount of concrete testing was carried out before the concrete deck was placed. The mix proportions tested in the laboratory indicated a 28-d strength of 45.7 MPa (6630 lbf/in²). This testing was followed by a substantial program of field trial batches

Figure 7. Inspection and testing time on bridge-deck concrete.

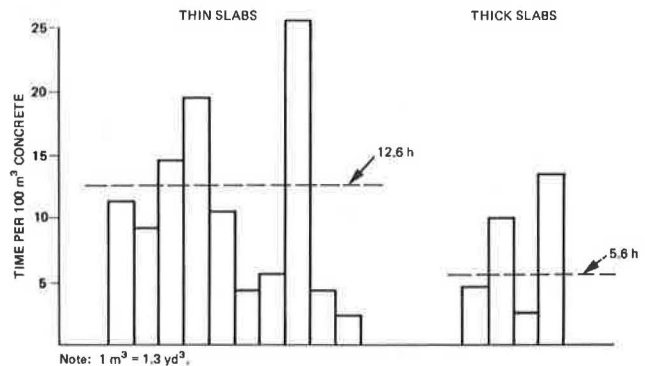


Table 1. Concrete compressive strength data.

Site Number	Concrete		Compressive Strength Tests				
	Class (MPa)	Quantity (m ³)	Total Number of Sets Made	28-d Tests		Mean 28-d Strength (MPa)	Percentage Failure (28 d)
				Made	Required ^a		
22-277	28	69	4	1	2	32.3	0
14-347	28	306 (2 pours)	12	4	6	40.7	0
14-348	28	78	9	3	3	34.5	0
46-124	28	226 (2 pours)	13	6	6	36.8	0
5-219	34	995	32	21	4	33.7	62.0
5-220	34	349	12	7	3	35.3	29.0
37-154	28	57	3	1	2	40.5	0
3-306	34	1970 (4 pours)	48	18	13	41.2	0
36-82	28	253	4	1	3	36.2	0
37-991	28	138	3	2	3	37.0	0
40-02	28	114 (5 pours)	14	5	10	35.3	0
33-291	34	516	16	5	4	40.2	0
37-963	28	240	6	2	3	32.7	0
37-1005	28	445 (2 pours)	10	4	6	40.4	0

Note: 1 MPa = 145 lbf/in²; 1 m³ = 1.3 yd³.

^aBased on requirements of concrete construction report. For 34-MPa (5000-lbf/in²) concrete, the frequency of testing may be greater than that specified.

with a mean 28-d strength of 41.2 MPa (5970 lbf/in²) for 12 separate mixes. Concrete slump, air content, and temperature of the field trial batches were all comparable to anticipated values for the bridge-deck construction. It is difficult to explain at this point why the designated mix proportions used on two bridge decks produced concrete with a compressive strength lower than earlier field trial batches by 5.9 and 7.4 MPa (850 and 1080 lbf/in²) respectively, but it emphasizes the need for rapid on-site tests and concrete plant controls that will ensure concrete mixes of the specified proportions.

On this contract, 7-d cylinder tests from one site were available before the construction of the deck at the other site, and the test results did indicate a potential problem with the specified 28-d tests. The use of accelerated concrete strength tests, a technique available to MTC inspectors, would have provided additional time to correct the problem before the second deck slab was constructed. As noted elsewhere, the average concrete placement temperature exceeded the specified maximum—certainly a factor contributing to lower strength.

Slump Tests

The required number of slump tests is based on testing at the beginning of the pour, at the point at which concrete cylinders are made, and at subsequent intervals to ensure that the specification requirements are met. In calculating the number of tests required (Table 1), satisfactory testing is assumed for the first five loads of concrete. A slump test has been added to this for each set of cylinders made. Because large numbers of cylinders for other than the 28-d test are often made and cylinders could be made from concrete in the first five loads, the required number of tests may be high in some cases.

An adequate number of slump tests were done on the 14 bridge decks included in the study, although in five cases the number was significantly lower than that required. The mean value of slump tests reported, contract by contract, was in each case greater than the maximum slump of 6.4 cm (2.5 in) specified for bridge decks. In recent years there has been a tendency in construction of bridge decks to accept a 7.6-cm (3-in) slump as a reasonable target value. In view of reinforcement congestion in some decks and the capability of typical bridge-deck finishing machines, the existing specification requirements on the consistency of bridge-deck concrete may be slightly unrealistic.

At site 33-291, a mean slump value of 15.5 cm (6.1 in) is reported for 58 tests (Table 1). The mean slump value of the concrete on this deck was obviously excessive although it is inflated by the inclusion of several very high tests from rejected loads and the concrete was apparently accepted on discharge from the truck at higher than specified values because of drying out on a long conveyor belt transportation system. The air content of the concrete on this particular deck-slab placement was apparently deliberately kept low at least partly to compensate for the effect on concrete strength of the high slump. The mean air content of 4.5 percent from 53 tests indicates that more than half of the concrete represented by the tests was below specification requirements, which is obviously not acceptable for MTC bridge decks.

Air Tests

The required number of air tests is based on the rate of concrete placement and the number of truckloads of

concrete delivered (Table 2). The concrete quantity has been used in conjunction with the inspection and testing time to determine if the rate of pour exceeds 38 m³/h (50 yd³/h). Because inspection time may be spent on prepour preparation, postpour finishing, and curing and protection procedures, the calculated pour rate may not reflect actual conditions. At placement rates lower than 38 m³/h, an air test is specified for each load of concrete. At rates in excess of 38 m³/h, it has been assumed that testing the first five loads will establish satisfactory control and one test every third load thereafter will maintain control. The size of the load also affects the number of air tests required. Because it is difficult to determine when larger loads were used, all calculations are based on 5.3-m³ (7-yd³) loads.

The required frequency of air tests stated in the concrete construction report (Figure 1) reflects MTC policy: All concrete in a bridge deck must be properly air entrained to prevent premature deterioration by freezing and thawing in the presence of deicing salts. Size and speed of bridge-deck placement operations require that a substantial effort be made to test the air content of the plastic concrete.

Apart from the one deck example already referred to, reported mean values for air content indicate that most tested concrete is properly air entrained. Only maximum, minimum, average, and number of tests are reported on the concrete construction report. It is apparent that on some very large deck-placement operations the district inspection staff is able to make the sizable number of air tests required. But this is not always the case; in fact, an insufficient number of air tests were made on 11 of the 14 deck slabs. In one example (site 5-220), seven tests for 349 m³ (457 yd³) of concrete are totally inadequate regardless of the capacity of the ready-mix truck or the rate of concrete placement.

Temperature Tests

Data given in Table 2 indicate that a sufficient number of temperature tests are being made for the purpose of determining conformity with specification requirements (this characteristic should show little variation in a given concrete-placement operation). For 34-MPa (5000-lbf/in²) concrete, in conditions in which the maximum concrete temperature requirement was 24°C (75°F) regardless of weather conditions, two of the four decks reported mean concrete temperatures greater than that specified. The study included several deck slabs placed under cold or near-cold weather conditions. At site 36-82, the mean concrete temperature reported from 20 tests [16°C (60°F)] coincided with the minimum specified value. This and lower minimum values reported indicate that some concrete was placed at too low a temperature.

General

Including results on rejected loads of concrete in the test summary appears to defeat the purpose of the concrete construction report. If an evaluation by the ready-mix supplier is required, an additional form tabulating the results of tests on rejected loads would serve this purpose better. The inspector's report would then more accurately indicate the quality of the concrete placed.

During the review of the concrete construction report, several omissions were found, e.g., volume of concrete placed, mean air temperature, number of tests performed. These omissions appear to be a result of carelessness on the part of the inspector compiling the form. Eliminating errors and omissions at the site office by

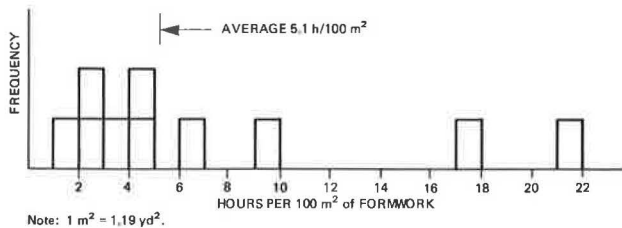
Table 2. Results of concrete slump, air, and temperature tests.

Site Number	Quantity of Concrete (m ³)	Slump				Air			Temperature		
		Tests Made	Tests Required	Tests per 100 m ³ of Concrete	Mean Value (cm)	Tests Made	Tests Required	Mean Value (%)	Tests Made	Tests per 100 m ³ of Concrete	Mean Value (°C)
22-277	69	5	9	7.2	7.6	8	13	6.0	8	11.6	21.7
14-347	306 (2 pours)	35	22	11.4	7.9	39	56	6.0	38	12.4	21.1
14-348	78	13	14	16.7	7.4	13	14	6.0	13	10.1	18.9
46-124	226 (2 pours)	32	23	14.2	7.4	32	42	6.0	32	14.2	21.1
5-219	995	9	37	0.9	8.9	43	65	4.8 to 7.0 ^a	40	4.0	25.6
5-220	349	5	17	1.4	7.6	7	25	5.0	8	2.3	24.4
37-154	57	3	8	5.3	7.6	3	11	6.0	1	1.8	17.8
3-306	1970 (4 pours)	69	67	3.5	7.4	233	157	5.5	183	9.3	13.3
36-82	253	12	9	4.7	8.4	14	47	6.2	20	7.9	15.6
37-991	138	13	8	9.4	8.9	13	26	6.3	13	9.4	23.3
40-02	114 (5 pours)	22	22	19.3	6.9	22	22	6.1	15	13.1	22.2
33-291	516	58	21	11.2	15.5	53	36	4.5	48	9.3	18.9
37-963	240	6	11	2.5	7.6	12	18	5.5	8	3.3	23.9
37-1005	445 (2 pours)	18	20	4.0	7.6	18	30	5.8	18	4.0	18.9

Note: 1 m³ = 1.35 yd³; 1 cm = 0.39 in; 1°C = (1°F - 32)/1.8.

^aMean value was not calculated in the concrete construction report.

Figure 8. Inspection time on bridge-deck formwork.



requiring that the supervising inspector or the project supervisor check the forms is advisable.

Bridge-Deck Formwork and Falsework

In this paper, falsework is defined as steel or timber shores, bracings, jacks, and foundations used to support the formwork. Formwork is defined as the plywood mold into which the fresh concrete is placed. Falsework is generally not used in the construction of thin-slab decks supported on steel or precast concrete beams.

Erection of formwork or falsework on many structures included in this project had started before the study began. To assess the value of an inspection effort on only a portion of falsework or formwork is practically impossible. Thus, only a limited number of complete falsework erections and formwork operations were recorded.

Figure 8 summarizes the inspection time reported for formwork on 10 bridge decks. The deck slabs varied from small, thin-slab structures with a soffit area of less than 170 m² (200 yd²) to very large, thick-slab, posttensioned structures with more than 20 times this area of formwork.

The average inspection time of 5.1 h/100 m² (120 yd²) of formwork represents 8 inspection days for a typical three-lane bridge 91 m (300 ft) in length. This amount of inspection time probably reflects the absence of other work to be inspected on the structure rather than the demands of the formwork. Inspection times for formwork, as may be expected, varied widely; more time was spent on slab-on-beam decks than on voided post-tensioned structures. Camber problems associated with simply supported beams generally require more inspection. Adequate inspection time is clearly available for checking the quality and accuracy of formwork construction.

The following table gives inspection times for the erection of falsework for three structures in two districts (1 m² = 1.195 yd²):

Site Number	Approximate Area of Deck Soffit (m ²)	Inspection Time (h)	Inspection Time per 100 m ² (h)
3-306	2211	30.5	1.4
3-303	3156	58.5	1.9
33-291	656	23.5	3.6

This small sample indicates that a substantial effort is put into falsework inspection by the district inspector. Although the data are insufficient to support recommendations on falsework inspection, discussions with various project supervisors and inspectors revealed wide differences in the handling of such inspection. Three methods seem to be in use in the province:

1. The district inspector accepts no responsibility for falsework erection and informs the structures office when falsework erection is complete. A structural inspection engineer then approves the falsework configuration.
2. The district inspector checks conformation with the approved falsework drawings during erection. On completion, the structural inspection engineer inspects and approves the falsework.
3. The district inspector assumes full responsibility for ensuring that the falsework arrangement is in agreement with the approved plan. The structural inspection engineer is consulted only on problems that the inspector feels are beyond his or her experience and ability.

There is clearly a need to establish uniform MTC inspection procedures for falsework.

Placement of Bridge-Deck Bearings

Inspection times for bearing placement, given below, indicate reasonable effort and uniformity of inspection for the bridges considered:

Site Number	Number of Bearings	Inspection Time (h)
29-194	24	18
3-304A	10	2

Site Number	Number of Bearings	Inspection Time (h)
3-314	9	1
36-82	70	7
46-199	10	2
33-291	6	1
37-963	80	3.25
30-432	24	3

The fact that inspection time was not reported for bearing placement at three sites seems to indicate that some district inspectors do not concern themselves with this process. The items that require the inspector's attention during bearing placement must be clarified.

Placement of Stressing Cable and Stressing and Grouting Operations

Head-office staff play an important if varied role in on-site inspection of cable placement, stressing, and grouting. The wide variations in inspection time expended by district-level staff reflect somewhat their varying degrees of responsibility. There may be good reasons for a particular inspection arrangement—e.g., a district may not have an inspector experienced in prestressed concrete—but the situation has led to some confusion on site as to what the district inspector is responsible for.

Data on inspection time for these operations, which were available for only four posttensioned deck slabs in three districts, are given below:

Operation	Site Number	Number of Transverse and Longitudinal Cables	Inspection Time (h)	Inspection Time per Cable (h)
Placement of stressing cables	5-219	91	24.5	0.27
	5-220	39	18	0.46
	3-303	126	5	0.04
	33-291	36	12.5	0.35
Stressing	5-219	91	18.5	0.20
	5-220	39	19.5	0.50
	33-291	36	62	1.72
Grouting	5-219	91	12	0.13
	5-220	39	13	0.33
	3-303	126	3	0.02
	33-291	36	27	0.75

The variation in the involvement of the district inspector is evident: Three hours to inspect the grouting of 126 cable ducts on site 3-303 is clearly partial inspection whereas 27 h to inspect 36 cables on site 33-291 may represent continuous inspection of the grouting operation. Cable placement in three decks received close attention from the district inspectors, but at site 3-303 much less inspection time was reported.

The proper checking of cable stressing requires continuous presence of the inspector to ensure that the specified strand elongations and jack pressures are achieved. Thus, inspection time depends directly on the speed and the efficiency of the contractor's operation. Stressing problems occur frequently, and many days of inspection time are sometimes needed. The inspection time spent on the three structures for which stressing operations were reported indicates full-time or almost full-time checking of the contractor's work.

Erection of Concrete Beams

The table below for the four contracts that reported data indicates that a reasonable inspection effort was put into the erection of precast concrete beams:

Site Number	Number of Beams	Inspection Time (h)	Inspection Time per Beam (h)
22-277	5	9.5	1.90
32-136	20	16	0.80
36-82	35	7	0.20
37-963	40	34.25	0.86

Waterproofing of Deck

The inspection times reported for bridge-deck waterproofing generally indicate reasonable uniformity. Since the daily report on bridge inspection was compiled by bridge inspectors, the lack of reported time on paving operations has indicated that this phase of the work is probably handled by the road paving inspector. This may be the best approach provided the road inspector is made aware that the waterproofing membrane must not be damaged during paving. Data for inspection time on waterproofing operations are given below ($1 \text{ m}^2 = 1.2 \text{ yd}^2$):

Site Number	Quantity (m^2)	Inspection Time (h)	Inspection Time per 100 m^2 (h)
22-275	2421	12.5	0.43
22-276	1007	6	0.50
46-124	924	7	0.63
5-219	1091	6	0.46
37-154	455	2	0.37
37-866	962	11	0.96
3-304A	2229	19	0.71
3-314	951	13	1.14
40-02	396	14	2.97

Excavation and Pile-Driving Operation

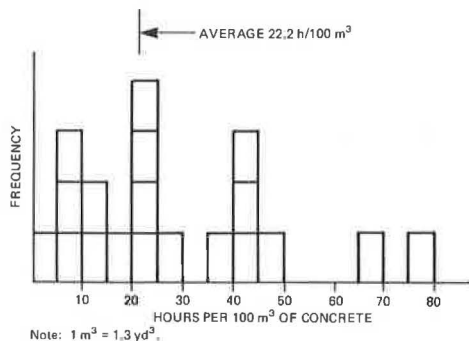
Considerable variation in the site conditions encountered during footing construction contributes to the difficulty of both construction and inspection. Although different soil conditions, dewatering problems, shoring and protection requirements, and location of the footing grade with respect to the original topography all affect footing construction, it is difficult to determine how much each affects the variation in inspection. Detailed examination of the footing excavation and pile-driving operations would probably reveal unique problems and methods of construction, which would often account for differences in inspection time. Although reasonable inspection time seems to have been spent on these operations, it is clear that some personnel assigned to inspect the driving of piles had little experience in such construction.

Footings and Substructure

As anticipated, considerably more inspection time per unit is required for the relatively small footing and substructure pours. Reasons for this include (a) similar prepour preparation and postpour curing and finishing operations distributed over smaller volumes; (b) less accessible sites, the necessary use of less efficient placement techniques, and rate-of-pour restrictions that result in slower concrete placement rates; and (c) problems of specification interpretation and construction techniques that are usually resolved before construction of the deck.

In some cases, trial batches to determine the suitability of 34-MPa (5000-lbf/in²) bridge-deck concrete mix designs have been placed in footings and substructure sections. Additional inspection and testing have been done in these areas. Test results indicate that most 20.7- and 27.6-MPa (3000- and 4000-lbf/in²) concrete

Figure 9. Inspection time on formwork of bridge substructure.



placed in footings and substructure conformed to the specification requirements. With few exceptions, the inspection effort and testing programs for concrete in bridge footings and substructure appear to be quite adequate. The following table summarizes this inspection and testing for all sites ($1 \text{ m}^3 = 1.3 \text{ yd}^3$):

Item	Total Concrete (m^3)	Mean Quantity of Concrete Represented by One Test (m^3)			Inspection and Testing Time per 100 m^3 of Concrete (h)
		28-d Cylinder	Air Content	Slump	
Footings	2194	38	11	13	11.8
Substructure	3609	40	10	14	13.3
Deck slabs	5757	72	11	19	6.3

Bridge Substructure and Formwork

In reviewing these data it is important to realize that many different substructure types are represented and thus wide variations in inspection times can be expected (Figure 9). Because the various structures represent a wide range of forming and inspection problems, it is difficult to make meaningful comparisons of inspection times. However, some contracts report what appears to be an excessive amount of inspection; three sites each with formwork quantities for less than 76 m^3 (100 yd^3) of substructure concrete, completed during the study, indicate an average inspection time of 3 person days for this quantity of formwork. The average formwork inspection time noted— $22 \text{ h}/100 \text{ m}^3$ (131 yd^3) of concrete—represents a much greater inspection effort than that for bridge-deck formwork. This increased inspection time reflects the more complex nature of vertical formwork and the greater area per unit of volume of supported concrete.

Site Visits

Bridge inspectors were asked to record the nature and the duration of site visits of MTC personnel above the inspector level during each bridge-deck concreting operation to determine the help and assistance normally available. District office construction supervisors, construction engineers, and district engineers spent an insignificant amount of time on site during placing of the deck concrete. However, on many contracts, the project supervisor, assistant project supervisor, or a supervising inspector was present, often for most of the working day. The influence of the regional office engineering staff is clear: A supervising inspector from that section was present on most sizable deck concreting operations. Head-office staff were seldom present during the concreting of a bridge deck. If difficult problems arise during concreting operations of a deck slab, the bridge inspector can normally seek help from the project

supervisor or the regional supervising concrete inspector, but guidance from MTC construction engineers or quality control engineers can only be obtained by telephone.

CONCLUSIONS AND RECOMMENDATIONS

The quality of a structure depends largely on workmanship in construction. The best of materials and design practice cannot be effective unless the construction is well performed. Competent inspection and adequate testing programs are necessary throughout the progress of the work to ensure a satisfactory finished product.

Assuring adequate structural quality through the prevention of construction faults may be more difficult for concrete bridges than for other civil engineering structures. The whole construction "team" is together for a relatively short period of time. Repetitive operations seldom occur on a bridge as they do on, say, a high-rise structure; on many contracts the contractor is performing a different operation from day to day. There is no "ground floor" on which to sort out construction problems. On some segments of the structure—for example, a posttensioned, voided deck slab—huge quantities of concrete are placed in a single day around a complex arrangement of voids, cables, and reinforcement. Once this concrete production, delivery, placement, and finishing operation gets under way, understandable pressure is put on the on-site staff against making decisions that will impede or halt the work.

This study of current inspection and testing programs, although somewhat limited in scope chiefly because the qualitative aspect of inspection is almost impossible to measure, leads to the following conclusions and recommendations:

1. The wide variation in inspection effort noted on comparable segments of different structures depends partly on the inspector's own interpretation of the scope and the nature of the required inspection effort. A practical bridge-inspection manual that explains in detail what and how structures should be inspected is needed as the basis for a uniform standard of quality. This manual plus appropriate checklists should be the basis for building more accountability into inspection work.
2. Improved manpower planning procedures are necessary to ensure that the required inspection effort and concrete testing programs are carried out. Further studies are needed to determine the optimum time required to complete inspection and testing programs on the various segments of a structure.
3. Site drawings, in particular those detailing reinforcing bars, are not easily interpreted by many inspectors. Simpler drawings are needed.
4. More use should be made of accelerated curing procedures for concrete test cylinders, particularly for prepour trial batches and laboratory mix designs. There is also an urgent need to develop reliable, practical tests for the rapid analysis of fresh concrete. Otherwise, extra controls such as mandatory printout of concrete proportions are required at ready-mix plants.
5. Current quality assurance problems in materials and workmanship can be minimized by strict adherence to existing specifications. There is a need to develop a broad attitude among the construction staff of the owner and the contractor that specifications, testing procedures, and other construction controls are something more than guidelines—that such documents must be the basis of construction, testing, and acceptance of the work.