SESSION 1

Inspection, Records and Maintenance

Surveillance, protocole de mesures et entretien

Überwachung, Zustandsprotokolle und Unterhaltung

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Supervision and Inspection of the Structures of the German Federal Railway

Surveillance et contrôle des ouvrages d'art de la Deutsche Bundesbahn

Überwachung und Prüfung der Kunstbauten der Deutschen Bundesbahn

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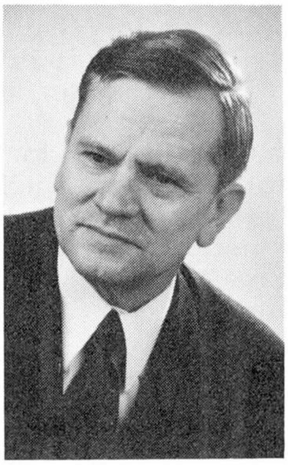

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SUMMARY
Regular inspections of structures contribute to the safety of the traffic using the structure and therefore to the safety of people and objects. Thus, the German Federal Railway fulfills its obligation to take responsibility for the safety and order of its fixed installations. Moreover, the quality of future structures can be improved by feedback of the damages found.

RESUME
Les contrôles réguliers des ouvrages d'art constituent une contribution à la sécurité du trafic franchissant les ouvrages et, partant, à la sécurité des personnes et des biens concernés. La Deutsche Bundesbahn satisfait ainsi l'obligation de répondre de la sécurité et du bon ordre de ses installations ferroviaires. Par ailleurs, l'analyse des défauts constatés peut contribuer à améliorer la sécurité des ouvrages futurs.

ZUSAMMENFASSUNG
Die Dauerhaftigkeit eines Bauwerkes hat neben den Ausgaben für die Erstellung entscheidenden Einfluss auf seine Kosten. Sie hängt wesentlich von der konstruktiven Ausbildung aller Bauwerksglieder ab. Die erforderlichen gestalterischen Regeln sind nicht mathematisierbar. Es wird beschrieben, wie die Deutsche Bundesbahn versucht, die Konstruktion dauerhafter Bauwerke zu erreichen.

1. 100 year history

Modern transport technology developed in parallel with bridge technology. The major indications on very old road maps are the fords and the very few bridges leading across the rivers whereas there is only vague information on the course of the actual roads. With the construction of the railways, bridge construction technology developed using in particular the new technical building material 'steel'. The advance of road construction after the invention of the automobile required highways with numerous bridges of dimensions unknown until then, leading to the development of the prestressed concrete construction method. A further phase of bridge construction was introduced for the new lines (NBS) of the German Federal Railway (DB) with numerous valley crossover spans for fast moving trains and trains with high loads.

The development of rail and road bridge construction becomes particularly clear by the length of lines which compared to the total distance involved lead via structures. Whereas this percentage is negligible in the older road network, it achieves approximately 1 % in a classical railway network. About 3 % of a modern highway and about 10 % of the new lines under construction lead via bridges.

A further distinguishing feature of modern transport systems is the very brief period in time during which they were mainly developed. Therefore, the distribution of the service life of the German Federal Railway's bridges shows a marked inconsistency. This same inconsistency can be observed in outlines in connection with the highway network which expanded considerably in the last decade and according to the existing planning for the new lines, in this area too, the construction of structures will concentrate to a few years.

The difficulties arising in connection with such concentrated construction work but also the manifold experience and the mutually stimulating technical developments fascinate all the experts, and keep the building and research industries in business. The rapid development is then followed by disillusionment, particularly with the "lucky" owners of these wonderworks of technology. One asks himself

- how long this splendour will last
- what is to be done when the wear and tear makes itself felt,
- what service life is to be expected,
- how much maintenance cost may be incurred,
- how the inspection is to be organized and
- how the safety of an existing structure is to be judged.

Dozens of questions, requiring an answer. Questions which were first asked 100 years ago and still have not been answered satisfactorily.

In 1873, the "presumable life of iron structures" was the subject of the delegates 'meeting of the union of German architects' and engineers' associations, as an old agenda shows (Fig. 1).

Schlußreferat

über muthmaßliche Dauer von Eisenconstructionen.

Vorgetragen

in der Ingenieur-Abtheilung der III. General-Versammlung des Verbandes deutscher Architekten- und Ingenieur-Vereine zu Dresden,

am 3. September 1878.

Von Dr. Hermann Fritzsche, k. k. Bezirksingenieur.

(Abdruck aus dem Organ für die Fortschritte des Eisenbahnwesens. Neue Folge. XVII. Bd. 1. Heft. 1880.)

Das Thema über muthmaßliche Dauer von Eisenconstructionen wurde, wie Ihnen bekannt, von der Abgeordneten-Versammlung des Verbandes im Jahre 1873 in Eisenach aufgestellt, zu weiterer Behandlung den Verbandsvereinen mitgetheilt und für die Tagesordnung der I. General-Versammlung des Verbandes, welche im September 1874 in Berlin stattfand, in Aussicht genommen.

Das Referat war dem sächs. Ingenieur- und Architekten-Verein, das Correferat dem Hannoverschen Architekten- und Ingenieur-Vereine über-
worden und hatte letzterer den Herrn Launhardt, ersterer
Vertreter gewählt.

Um allzuweit führende Wiederholungen
Inhalt meines Referats nicht näher
ständigen Abdruck desselben
Jahrgang 1875, Heft

Der

Figure 1: Final report

The following apprehension was expressed: "After a period of 50 to 100 years, the old iron structures might start to show breaks more frequently than we anticipate at the moment". They were of the opinion that "the collapse of an iron structure would not necessarily be caused by molecular changes - metal fatigue as we call it today - but by rust and that this collapse would be preceded by easily visible deformations" and the following was decided: "We recommend that repeated checks of iron structures be undertaken using the same methods and that a standard form for the collation of this information be introduced".

In 1878, the time had come: They agreed on a standard form in accordance with which the results of deflection measurements and some other major data on iron bridge girders were to be recorded.

In 1895, the Prussian State Railway Administration introduced "Regulations for the supervision and inspection of bridges with iron superstructure". Instructions were given to carry out detailed inspections at regular intervals. One distinguishes between annual inspections and main inspections at 5 year intervals. All the findings obtained are to be entered in a bridge book, where all major technical data are recorded, too. Material samples are to be kept of important bridges. It is then indicated which parts of the bridge special attention is to be given to during the inspections. A major part of the main inspection is the load test which is to supply information on the safety of the bridge. Thus, one also reckons to be in a position to judge the carrying capacity, with respect to lateral oscillations and vibrations, which cannot be calculated.

2. A modern system

The checks serve as basis for repair and renewal, which is to be arranged by the railway district operating offices in simple cases, if the checks were more costly or timeconsuming, they would be arranged by the Regional Headquarters. Special emphasis is to be placed on paragraph 15 of those regulations which says: "The officer carrying out the inspection must inform the superior Regional Headquarters on the experience to be gained on the appropriateness of the inspection regulations as well as the more or less good results obtained in practice with the various types of construction and individual forms for the purpose of putting them to use in future draft plans".

Truly, a very modern regulation in terms of cybernetic administration. It is not the purpose of this lecture to investigate whether there are further or more interesting documents from the beginnings of the railways concerning the inspection and supervision of railway bridges, the examples selected at random, spotlight this in a remarkable way. They are followed by further data taking into account the changed forms of organization of the railways. In 1926, this was the "Regulation for the supervision and inspection of bridges, halls and roofs", in 1940 a new edition of this regulation was published and the 3rd edition followed in 1956. This development is continued with the introduction of the "Regulation for the supervision and inspection of structures" (VÜP) DS 803 of the German Federal Railway, effective as of January 1, 1981.

This means, approximately 100 years of supervision and inspection of structures: What has changed, what has remained, what was achieved? In the more recent history of technology, the railways are the first owners of such a large number of valuable structures spread over a wide area. They could perhaps be compared with the major cities with their ramified public utility and waste disposal structures the maintenance of which is of vital importance for the entire population and the inspection, supervision and repair of which raise problems of documentation, know-how, costs and feasibility without the efforts and the success being correctly recognized and appreciated by those concerned. Nevertheless, the problems of judgment and conservation of railway bridges are of a different nature. Similarities can, however, be expected with regard to modern road bridges; the problems for the road construction agency will only become more critical one generation later, as it is the case at the moment for the condition of railway bridges. Reason enough to enter into a close exchange of experience with railway administrations and road construction agencies worldwide on the subject of renewal and maintenance, supervision and inspection of bridges. The views and experience of the German Federal Railway (DB) may be a contribution to this.

One thing is sure, if one had carried out all the required checks in the required order over the past 100 years, today excellent figures would be available to the railway administrations. If one then evaluated these figures by means of modern statistical methods, numerous questions would be answered. One may regret it, presumably the regulations were not adhered to with the required conscientiousness or where they were adhered to and books were kept, they were lost in turbulent times, or the bridges were renewed and the old books were put aside, or it is too troublesome to search in the yellowed documents or the technical solutions are so outdated that no conclusions can be drawn today from these behaviour patterns; the fact of the matter is that the German Federal Railway (DB) does not have any figures from that period at its disposal, which would supply information on the condition, on the fact whether good results were obtained in practice, on the maintenance costs or estimated renewal.

The desire to have such figures at one's disposal still exists as it did 100 years ago, therefore the 1981 regulations largely concern the recording of these data. Today's records shall also serve as basis for renewal and repair of the loadbearing parts. Special attention is attached to the feedback regarding the observed success in practical operation of the structural design of details. As you see, major parts of the supervision instructions remained unchanged. There was a change as regards the number of the components to be inspected on structures: For bridges not only the superstructures, but also the bridge supports, abutments and foundations have to be supervised; to this one added the load-bearing parts of halls and roofings as well as high retaining walls, chimneys and masts. There was a change of attitude towards load tests as means of checking the safety of the loadbearing parts. The implementation of this load test is questionable, expensive and interferes with operation and therefore is only carried out upon special order, above all in case of complicated loadbearing parts in connection with strain measurements in order to answer questions of spatial carrying capacity. In conjunction with calculated assumptions, spare carrying capacity that might exist can be determined. One also considers obtaining, by low-cost "normal measurements" by means of load test waggons available to the German Federal Railway (DB), statistical data on the "normal behaviour" of loadbearing parts of the same kind in order to gain wellfounded data on the difference between "theoretical and actual behaviour. This can extend the findings concerning the design methodology and possibly simplify matters, and in the case of old loadbearing parts significant deviations might lead to judging changes, as was expressed in the first supervision instructions.

3. Present procedure

The question remains whether the most recent statement tries to translate the desires into reality; for this the organization of supervision and inspection is to be described. 30 000 rail and road bridges (Fig. 2) exist in the area of the 10 Regional Headquarters, for each of the Regional Headquarters 2 bridge inspectors are available. The main inspections are to be carried out every 6 years, i.e. one bridge inspector must inspect approximately 150 bridges over the period of one year (Fig. 3).

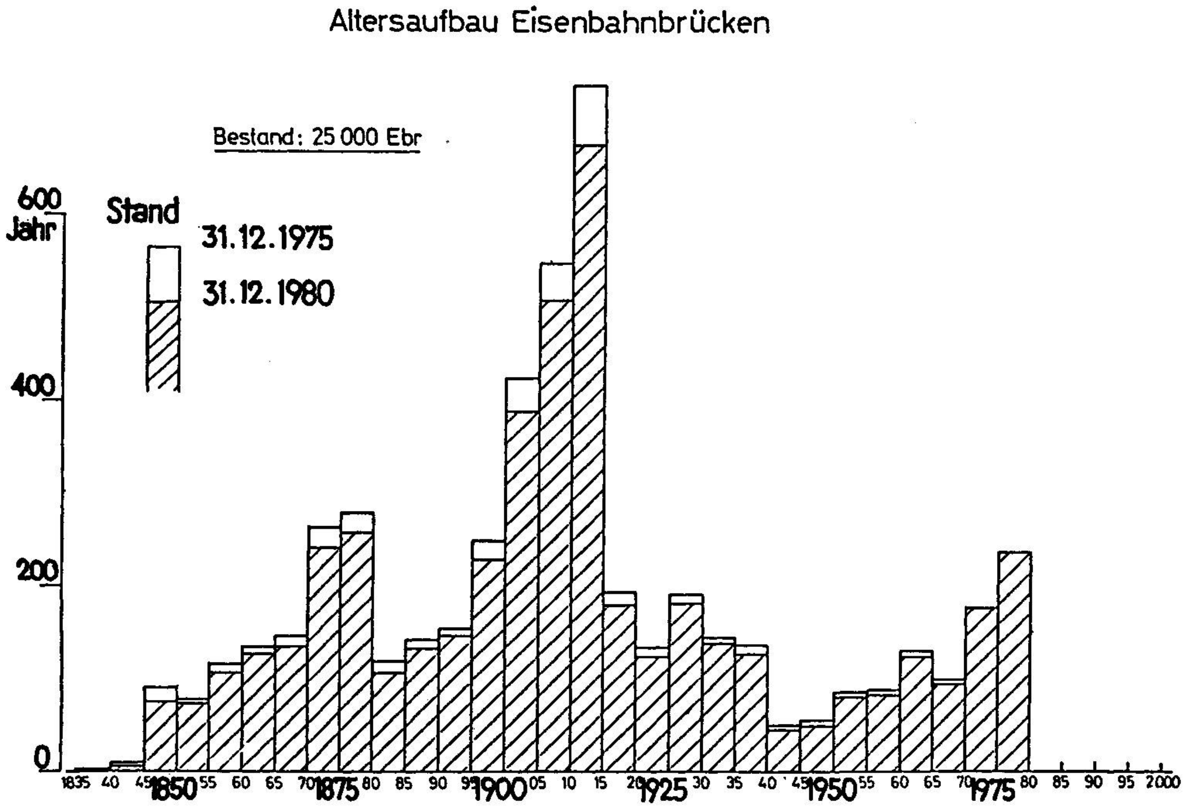

Figure 2: Age-structure of DB-bridges

DB/ZFB FRANKFURT (M) 13A.1352 -RUF 955/5064- 09.12.81
BD MUENCHEN BUREAU D -RUF 962/1449-

JAHRESPRUEFPLAN FUER BRUECKEN PRUEFJAHR 1982.

BD HANNOVER

STRECKEN-NR. 1424 STRECKENNAME: VON Abzw. Utbremen.......... BIS Bremen Rbf. . G.-Bahn LAGE: KM VON 0.103. BIS 4.326

ZU LFD.NR. 003 DES GESAMTJAHRESPRUEFPLANES GEMAESS DV 803 (VUEP) BA/BM. Bremen 1 . . Bremen..................

BA/BM...

SEITE 1

LFD. NR.	BRUECKEN-NUMMER	LAGE KM	BAUWERKSBEZEICHNUNG	BRUECKEN-LAENGE	BRUECKEN-BREITE	ANZAHL OEFFNG.	DER TRAGW.	TRAGWERKE IN BAUWEISE STAHL	STAHL+MASSIV	MASSIV	KLEINSTER BETA-S-WERT	ERSTELL. JAHR FRUEH.	ERSTELL. JAHR SPAET.	BRUEKKEN FLAECHE	ANSTR. FLAECHE	ABD. FLAECHE	GEPRUEFT VON	GEPRUEFT BIS
1	1.21260	0.332	EBR UE SALZBURGERSTRASSE	13,6	6,30	1	1	0	1	0	100	1915	1915	86	0	75		
2	1.21270	0.478	EBR UE PASSAUERSTRASSE	13,7	5,10	1	1	0	1	0	100	1915	1915	70	0	58		
3	1.21280	0.525	EBR UE BAB ZUBRINGER FREIHAEFEN	30,6	4,80	2	2	0	0	2	100	1962	1962	147	0	66		
4	1.21290	0.735	EBR UE NEUEN KAMPE	13,7	5,10	1	1	0	1	0	100	1915	1915	70	0	72		
5	1.21300	0.965	EBR UE DEN HOHWEG	13,6	5,05	1	1	0	1	0	100	1915	1915	69	0	59		
6	1.21310	1.329	EBR UE FLEETSTRASSE	13,6	5,05	1	1	0	1	0	100	1915	1915	69	0	59		
7	1.21321	4.373	EBR UE HALMER WEG	11,6	33,50	1	1	0	1	0	100	1914	1914	389	0	384		

Figure 3: Auval inspection plan

To prepare the inspection, an inspection team under the direction of an experienced foreman, cleans the structure and records the damages discovered on a diagnosis sheet and/or damage sheet (Fig. 4). The bridge inspector himself will then continue the inspection and assesses the existing damages on a findings sheet using his judgment as an engineer. In order to achieve a homogeneous judgment of the condition of structures with the purpose of controlling the input of capital and engineer's capacity on a mediumterm basis, uniform checklists were introduced. The findings of an inspection are to be entered in those lists in a uniform manner. In order to relieve the inspector, the data of the structure from the fixed installations inventory file are printed on the findings sheet by means of central data processing systems (Fig. 5). For all bridges to be inspected in a certain inspection year, the inspector receives the findings sheets prepared in the manner described above at the beginning of the year. At the same time, the structures to be inspected are also compiled on lists (Fig. 3).

The inspection results are entered on the findings sheets at the respective site by checking off. The major decision is the appraisal of the findings. In this connection, it must be decided for each component printed on the sheet whether it can be considered

- okay = A
- whether it requires maintenance = B or
- whether it requires renewal = C.

If renewal or maintenance work is necessary, an immediate attempt at roughly estimating the costs is to be made. Furthermore, ideas on the type and periods for this work will be given.

On this basis of the data entered for the various components of the bridge, the inspector then proposes a decision for the entire structure regarding

- the costs of the project and the agency responsible for the repair and

- the currently existing carrying capacity of the structure.

That means that he has to decide whether the structure meets the requirements for railway operation without any restricitions or whether the speed or load of the trains must be reduced pending the implementation of the required construction schemes. For this purpose, it ist necessary that the inspector submits statements relevant to safety and costs: Only very experienced engineers are suitable for such tasks.

Deutsche Bundesbahn

Diagnoseblatt [1]) für Widerlager, Pfeiler, Stützen, Flügel, Stützmauern Nr. 2

1											2
Bauwerksnummer											Kz
1	2	3	4	5	6	7	8	9	10	11	12
				1	3	1,	2	1	2	6	0

Bemerkungen: 1) Nichtzutreffendes streichen. 2) Fehlendes nachtragen. 3) Zutreffendes ankreuzen. In den Spalten 20 bis 47 und 53 bis 63 die Schadensziffer 1, 2 oder 3 eintragen.

3	4 Bauteil Nr. 2)	5 Bezeichnung 2)	6 Mauerwerk 3)	7 Beton 3)	8 Stahlbeton 3)	9 Spannbeton 3)	10 Stahl 3)	11 2)
1	0 1	Widerlager			X			
2	0 2	"			X			
3								
4								
5								

Festgestellte Mängel ○ = Instandgesetzt

12 Nr.	13 Bauteile, Bauglieder 2)	Zusätzliche Lokalisierung 2)	14 Bauteilbez. 2)	15	16	17	18	19	20 Risse: Längsrisse	21 Querrisse	22 Schrägrisse	23 2)	24 Sichtflächen: verwittert	25 naß	26 Ausblühungen	27 Fugen: Mörtel mürbe	28 offen	29 2)	30 Ausbruch: Abplatzung	31 Steine fehlen	32 Bewehrung frei	33 2)	34 Korrosion: einzelne Stellen	35 durchgerostet	36 Verformung: Ausbauchung	37 Überhang	38 Verschiebung	39 2)	40 Verankerungen	41 Bewuchs	42 Lager: Verankerung lose oder beschädigt	43 Unterbrückung schadhaft	44 Stellung veränd.	45 2)	46 Sonst. 2) nicht	47 2)	48 Ausf. 3) durch: Bm	49 Brm	50 Unternehmer	51 BD 3) überprüf.
6	Widerlager									1					1																				1					
7																																								
8	Auflagerbank																																							
9																																								
10	Kammermauer																																							
11																																								
12	Flügel									1					1				1		1																			
13																																								
14																																								
15																																								
16	Pfeiler																																							
17																																								
18																																								
19	Stützen																																							
20																																								
21																																								
22	Stützmauer									1									1		1																			
23																																								
24	Dehnungsfugen																																							
25	Brüstungen																																							
26																																								
27	Abdeckungen																																							
28																																								
29	Abdichtung																																							
30																																								
31	Kabelkanal																																							
32																																								
33	Gehweg																																							
34																																								
35	Geländer																																							
36																																								
37																																								
38	Werben																																							

52 Nr.		53	54	55	56	57	58	59
	Entwässerung	verstopft o. verschmutzt	Rinne/Rohre 1) Tüllen schadh.	2)	Ausführung durch B=	Bm	Unt.	BD 3) überpr.
39								

60 Nr.		61	62	63	64	65	66	67
	Böschungskegel Dammabschluß	Böschung abgerutscht	Bewuchs beseitigen	2)	Ausführung durch B=	Bm	Unt.	BD 3) überpr.
39								

Sonst besteht kein erkennbarer Mangel von Belang.

68 Nr.		69	70	71	72	73	74	75	76	77	78	79
	Ursachen der Mängel 3)	Verschleiß	Überbeanspruchung	Ermüdung	Materialfehler	2)	Bauausführungsmängel	Überalterung	Witterungseinflüsse	Unterhaltungsrückstände	fehlender Korrosionsschutz	DB Unfall/ Anprall Dritter 1)
40		X							X			

80 Nr.		81	82	83	84	85	86	87	88	89	90	91	92
	Beseitigung der Mängel 3)	nichts zu veranlassen	Arbeitsplan BA/Brm < 15 TDM	Bauvorhaben: BD Vorh. 15-500 TDM	HVB Vorh. > 500 TDM	Ausführungsart: Instandsetzung	Teilerneuerung	Vollerneuerung	Frist: sofort	2 Jahre	6 Jahre	geschätzte Kosten TDM 2)	Bemerkung
41		X											

Bemerkungen:

Das Bauteil entspricht ~~nicht 1)~~ - ~~eingeschränkt 1)~~ den Anforderungen. Weiteres siehe Befundblatt.

Bremen, den 22.10.76

[signature]

Name und Funktionsbezeichnung des Prüfenden

803 32 Diagnoseblatt für Widerlager, Pfeiler, Stützen, Flügel, Stützmauern A4D 4x4a60 Köln I 75 15000 B 300

Figure 4: Diagnoses sheet

Deutsche Bundesbahn **BEFUNDBLATT**

Zum Befund gehören: 1 Befundblätter, ___ Diagnoseblätter, ___ Schadensblätter, ___ sonstige Anlagen, ___ Fotos

1. Allgemeine Angaben (Anleitung vgl. DS 803, Anlage 10, Rückseite)

BD	HANNOVER
BA	BREMEN
Bm	BREMEN
Strecke	ABZW UTBREMEN BREMEN RBF
km	0,332
Bauwerk	EBR UE SALZBURGERSTRASSE

1	2
Bauwerks-Nr.	
13 1.21260	

Hauptprüfung am: 27.10.81

Sonderprüfung am: ___

2. Bauteile **3. Entscheidung für die Bauteile** 3)

3 Teilblatt	4 Abschnitt Zeile	5 Öffnungs-Nr.	6 Bauteil-Nr.	7 Bauteilbez.	8 Baustoff	9 Bauweise	10 Baujahr	11 Wertung A	12 Wertung B	13 Wertung C	14 nichts zu veranlassen	15 Instand-setzung	16 Teiler-neuerung	17 Voller-neuerung	18 Verfüllen	19 Verrohren	20 Verschleißen	21	22 Frist zur Erfüllung d. Maßnahme: sofort	22 2)	22 6 5) Jahre	23 geschätzte Kosten TDM 2)
00	10	00	01	1	4	14	1915	X														
00	11	00	02	1	4	14	1915	X														
00	20	01	01	1	1	45	1915	X														
00	21	01	01	1	4	45	1915	X														

(Ausführungsart - Maßnahme 5))

4. Entscheidung für das Gesamtbauwerk 3)

4.1 ☐ HVB-Vorhaben ☐ BD-Vorhaben ☐ Arbeitsplan geschätzte Gesamtkosten TDM: ___

4.2 Das Bauwerk entspricht: ☒ den Anforderungen ☐ eingeschränkt den Anforderungen ☐ nicht den Anforderungen

Grund: ___

4.3 Betriebliche Maßnahmen: ☒ nicht erforderlich ☐ erforderlich ☐ LA-Stelle ☐ Lastbegrenzung

4.4 Sonstige Maßnahmen: ☒ nicht erforderlich ☐ erforderlich

Bemerkung zu 4.1 bis 4.4: ___

Datum: ___ Unterschrift: ___ Bktr./Br Prüfing. 1)

5. Nebenprüfung-Befund 3) Dazu gehören: 4 Diagnoseblätter, ___ sonstige Anlagen

	ja 4)	nein
Höhen-, Lastbegrenzungsschilder, Leitmale fehlen 1)		
Anprallschäden von Straßenfahrzeugen sind vorhanden		X
Veränderungen gegenüber der Hauptprüfung wurden festgestellt		X
Die Verkehrsbedeutung der Straße, des Wasserweges hat sich geändert		
Planungsänderungen für das Bauwerk - Kreuzung - sind bekannt		X
Sonderprüfung durch BD ist durchzuführen		X

Bemerkung: ___

Das Gesamtbauwerk entspricht: ☒ den Anforderungen ☐ eingeschränkt den Anforderungen ☐ nicht den Anforderungen

Datum: 27.10.81 Unterschrift und Funktionsbezeichnung: ___

803 10 Befundblatt A4 5c 70

Figure 5: Findings sheet

The inspector's decisions are compiled in an annual inspection results schedule which is the continuation of the annual inspection schedule printed out by Elektronic Data Processing (EDP). This schedule allows a quick survey of the construction work to be carried out in the coming years.

The final decision on the further procedure ist taken on this basis by the Head of the Bridge Construction Department of the Regional Headquarters in agreement with the bridge inspector and the planning engineers responsible for the respective area and is laid down in the annual inspection decision schedule (Fig. 6).

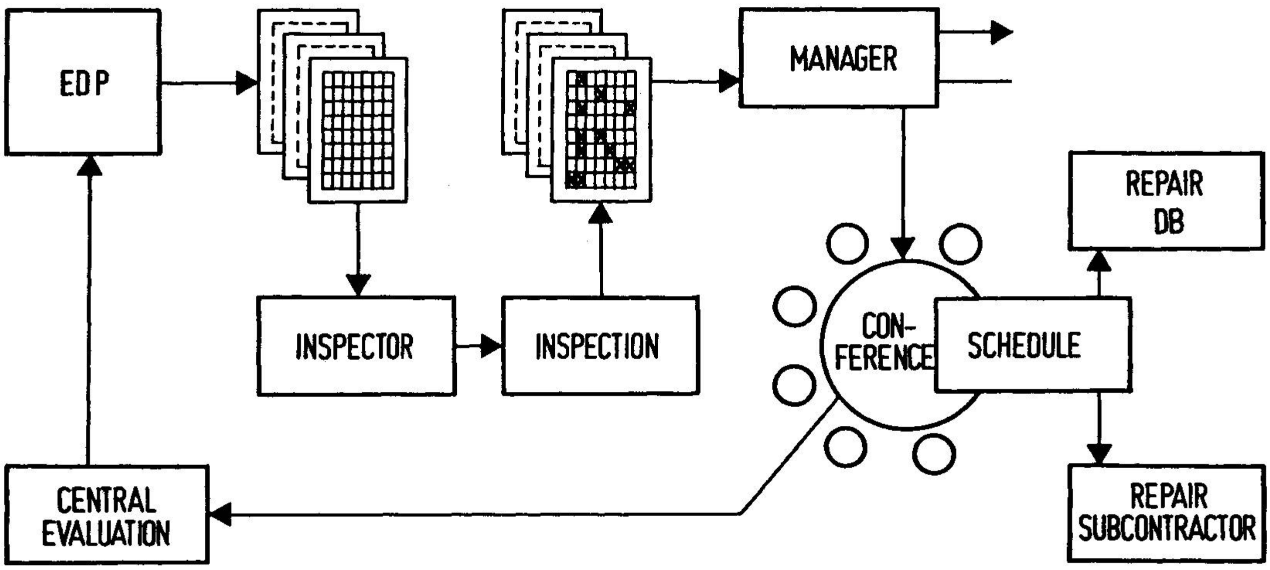

Figure 6: Procedure plan

These decisions together with those of the preceding years and the desires to change structures or build new bridges will then constitute the bridge construction programme of a certain year which is subject to further agreement processes for taking into account the financial situation and the company targets. This explains the long preparatory period required for planning necessary renewal in due order. At the moment the German Federal Railway spends approximately 250 million DM annually for the renewal and maintenance of the bridges in the existing network. The expenditure for a main inspection amounts to about 1 000 DM on the average.

For the main inspections, data are required on the type of construction and particularly sensitive or critical components. As such documents were lost in most cases during the last wars, special attention must be attached to this prerequisite when establishing new bridge books.

All findings of the main inspection are entered into the bridge book so that it will be possible to fill this past gap as time goes by. On the findings sheets themselves there will be enough space for entering the results of the intermediate inspections. Intermediate inspections of a bridge take place once between two main inspections.

They are carried out by the local engineer responsible for all constructional and operational matters, the Divisional Manager. No special preparations are made on the structure. In the intermediate inspections it is to be checked by means of visual inspection whether the condition - as laid down on the findings sheets - of the structure or the surroundings, for railway overbridges for instance also the overhead clearance for motor vehicles, have changed in a manner that might have an impact on the bridge. Special attention has to be attached to the fact whether, for instance, waterways were by-passed or road were "undedicated", no longer requiring a bridge or whether at least the dimensions could be reduced. In most cases, local agencies know of such dircumstances earlier and have more details than the large central offices.

4. Prospects

The existing organization with EDP support quite useful at the present stage ensures

- a complete inspection of all structures of the German Federal Railway (DB),
- an inspection carried out on schedule,
- avoiding staff-intensive manual recordings and their reproduction and thus a reduction of inspection expenditure by about 20 %,
- a uniform procedure for the entire German Federal Railway (DB),
- a high efficiency of inspection as numerous aids are provided by the obligation to make a statement,
- well-founded figures on the condition of an important part of infrastructure,
- foresighted planning for re-investment in the area of bridges,
- coordination of the planned re-investment with the functions and targets of the company as well as
- useful experience regarding the success in practice of the various construction methods and construction details.

The last of the above items requires that those first mentioned be fulfilled. Therefore, every effort ist made at the moment to ensure that the findings on diagnosis sheets have an interpretative quality of the same standard. All lists are set up in a manner allowing their data being easily recorded on data carriers, updated an statistically evaluated. First attempts have been made and new constructions were derived from the results. Trend-setting steering data from the evaluations are to be expected shortly. They will certainly not only please railwaymen and politicians, but also be useful for finding the narrow path leading the railway along the abyss and also leading the sensitive railway infrastructure into the future.

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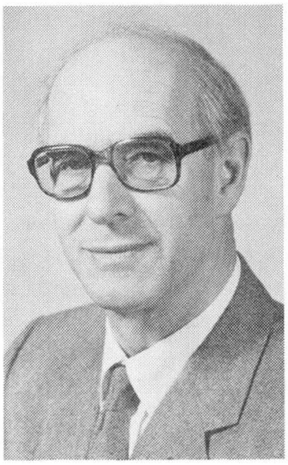
Highway Bridge Inspection: Principles and Practices in Europe

L'inspection des ponts routiers en Europe: principes et pratique

Grundregeln und Praktiken bei der Strassenbrückeninspektion in Europa

W.I.J. PRICE
Partner
Gifford & Partners
Southampton, UK



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SUMMARY
The state of the art of Bridge Inspection in Europe is reviewed and certain general principles and practices identified. The purpose and classification of systematic inspection and the formats of inspection reports are discussed. Instrumental aids to inspection are assessed and the prospects for automated monitoring examined.

RESUME
Le rapport passe en revue les récents développements dans le domaine de l'inspection des ponts en Europe et met en évidence certains principes techniques généraux. Le but et le classement des types d'inspection systématique et la présentation des rapports d'inspection sont discutés. Les instruments pour l'inspection sont évalués et les perspectives d'automatisation examinées.

ZUSAMMENFASSUNG
Die Arbeit untersucht den Stand der Technik bei der Brückeninspektion in Europa und zeigt bestimmte allgemeine Grundregeln und Praktiken auf. Zweck und Klassifizierung einer systematischen Inspektion sowie die Art der Inspektionsberichte werden diskutiert. Instrumentelle Hilfsmittel für die Inspektion werden bewertet und die Aussichten für eine automatisierte Kontrolle untersucht.

1. INTRODUCTION

Inspection is an essential ingredient in the assessment, maintenance, repair and replacement of bridges and, in a broader context, it provides the feedback of information on performance in service to design and management. The primary justification for inspection is the promotion of the safe passage of highway users, coupled with the protection of capital invested in bridges, with the minimising of operational cost and interference with traffic flow [1]. In addition there are many secondary reasons for inspection which arise from legal, social and political considerations, such as fear of legal liability, of unfavourable publicity, of political embarrasment, and loss of revenue and of professional and national reputations or prestige.

The emphasis on safety is in harmony with the evolving design philosophy of limit states [2]. These are limiting conditions beyond which a structure or element is assumed to become unfit for its purpose. They may be broadly classified either as ultimate or collapse limit states or as serviceability limit states. Catastrophic collapses of bridges in service causing personal injuries are, fortunately, rare, but even so the public is unwilling to accept any risk of collapse even though technical and economic considerations show that this cannot be achieved. In such circumstances, inspection provides a check on unforseen and unfavourable developments and gives the public a measure of assurance and confidence that is unlikely to be provided by a rational assessment of risk.

The serviceability limit states having a direct bearing on inspection are cracking, deflection, displacement, deformation, vibration and loss of material. Limits for such states are more difficult to define and quantify than those for collapse because they have to be related to the circumstances in which they occur and they may only need to be set in terms of the secondary effects they produce. For example, flexural cracking of a reinforced concrete beam may be of little structural consequence until it produces corrosion of reinforcement. Furthermore, each bridge has a certain uniqueness even though there is some standardisation of design and of components. It is likely that feedback of information from inspection will assist with sharpening the definitions of serviceability, and with identifying their practical effects.

On a more parochial level, further purposes of inspection can be identified as:

- Detection of actual and potential sources of trouble at an early stage; the "stitch in time" philosophy.
- Systematic recording of the state of the structure.
- Checking the effects of changes in construction materials and techniques, in permitted loads and in the environment.
- Providing information to make remedial action more cost effective.

2. TYPES OF INSPECTION

Whereas the inspections carried out during construction of a bridge are solely concerned with its quality and the quality of its elements, the in-service inspections are also concerned with changes in quality over a period of time. They are, therefore, some measure of reliability, if the latter is defined as the probability that the system will operate without failure for a given time under given conditions. A distinction is drawn between periodic inspection and breakdown inspection; the former is carried out on a regular basis, the latter being done when there are signs of failure. Over the past decade there has been increasing emphasis on periodic inspection, justified more by social and safety reasons than by economic ones. It has gradually become more structured and systematic, to improve its effectiveness. Expediency and restraints on resources will, however, ensure that many inspections are only done in association with a degree of breakdown and urgency.

Bridge inspection practice, in Europe, as reviewed by the OECD Road Research Group in 1975 [1], can be broadly classified, in terms of its intensity, frequency and scale, in the following categories:

- Superficial Inspection. This is carried out by maintenance personnel as and when they are in the vicinity of the structure. Only major defects or damage will usually be detected.
- Principal Inspection. This is carried out by trained personnel at regular intervals at two levels of intensity and frequency. The general inspection will be made at intervals of one to two years and the major inspection, requiring close and thorough examination, will be made at intervals of three to six years. Written, diagramatic and photographic records will be kept of the more important observations.
- Special Inspection. This will be carried out in unusual circumstances, for example, when there are signs of serious damage or when the bridge has to be reassessed for changes in loading or environment.

The principal inspection falls into the category of periodic inspection whereas special inspection is of the breakdown type.

This empirical classification reflects the complex interaction of a large number of factors, such as life expectation of bridges and their elements, their rate of deterioration, the consequences of unserviceablity and failure and the resources available for inspection and maintenance. These are difficult to quantify, but they need to be considered in the examination of present practices and the identification of trends for the future.

2.1 Rates of Deterioration

It is accepted in design that different elements will deteriorate at different rates. Those which are renewable or replaceable without loss of safety can have relatively short lives, for example surfacings, joints and guard rails. Their replacement does, however, carry the economic penalty of interference with traffic. With respect to setting the frequency of inspection, it is the shortest period for replacement which is of primary interest and, for the elements referred to, this can be as short as 5 years. The condition of many of them can be very adequately assessed by a superficial inspection and any secondary consequences of their deterioration, for example, the effects of water penetration through waterproofing and joints, examined in more detail during a general or major principal inspection. This implies that at least two principal inspections would be required to recognise trends in performance before early failure, which, in turn, determines a period of around not more than about 2 years between general principal inspections. For major elements of a bridge whose failure might precipitate or constitute collapse, the life expectation is very much longer, normally between 60 and 120 years. In the British design rules [3], for example, there is an expectation of a life of 120 years with a probability of failure in fatigue of about 2.5%. Taking all forms of degradation into account the European mean life expectation is around 60 years and actual life may be as low as 20 years. As the major principal inspection addresses itself to all structural details, a frequency for it of at least 2 per 20 years seems desirable. In manufacturing industry there is a reasonably well established procedure for relating reliability of a system to the failure rates of its elements [4]. For reasons discussed in the Introduction it is not possible to translate this directly to bridge reliability or serviceability. However, some general ideas might usefully be borrowed and perhaps used as a framework for future collection and analysis of data. It will not be possible to collect meaningful data on failure rates, because the numbers of identical elements subjected to the same in-service conditions will be very small and incidence of complete failure rare. However, if a measure of deterioration is substituted for failure then similar patterns of performance are discernible. For example, the length or width of cracks, or both, might be used as a quantitative measure of deterioration and its rate of change with time would be expected to show the "bath tub" form of Fig 1 experienced with failure of manufactured articles.

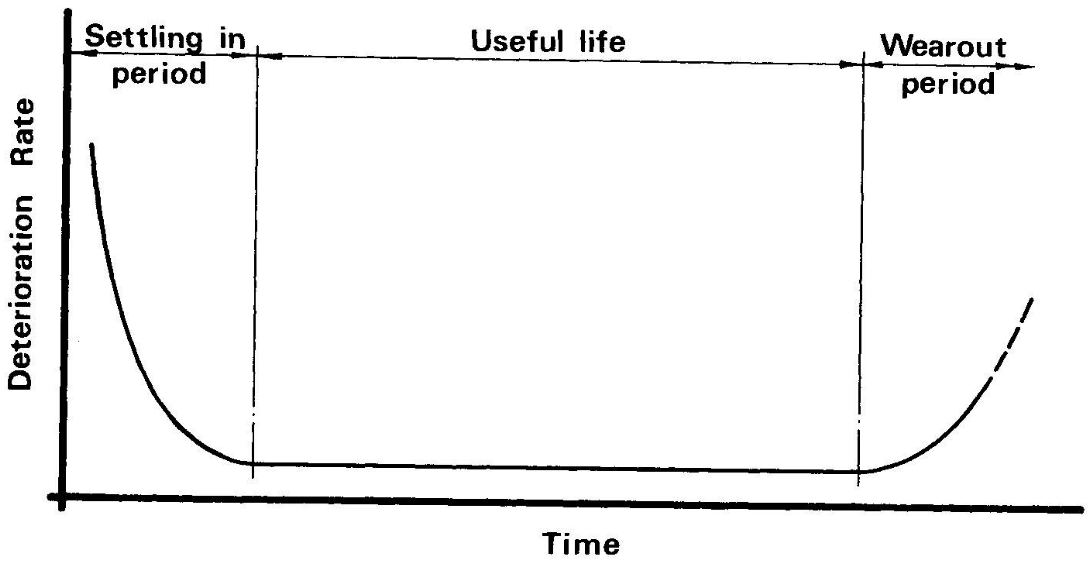

Fig. 1. Change of rate of Deterioration

Defects will become apparent in the early life of an element due to imperfections inherent in the material or introduced in the construction processes. Many of these may be rectified by the constructor during the contract maintenance period immediately following the opening of the bridge to traffic. Gradually such defects will become less frequent until the deterioration rate levels off to a low value during the period marked in Fig 1 as "useful life". A constant deterioration rate will be synonymous with random occurrence of defects. Eventually there will be a significant increase in deterioration rate as the element enters the wear out period of its life, when decisions will have to be taken about repair, rehabilitation or replacement.

The concept of a constant rate of failure, k, provides the following simple relationship between the reliability, R, after a given time, t, in service:

$$R = e^{-kt} \qquad - (1)$$

in which the failure rate will be defined as the number of failures, n, in the accumulated hours in service of all comparable elements, Nt, subjected to comparable conditions, so that

$$k = n/Nt \qquad - (2)$$

If this concept is applied to the bridge as a whole and, if it is assumed that all bridges fail at a 100 year life, the equivalent failure rate would be about 10^{-6} hr^{-1}. The Bridge Administration of Rheinland - Pfalz, Germany applied the reliability concept to the performance of a sample of bridges in service, defining k as a function of failure mode and maintenance intensity [5].

The mean time before failure, Ø, defined as the sum of the number of hours in service per failure, for a constant failure rate, might be regarded as a pointer to desirable inspection frequency. Ø will be the reciprocal of the failure rate, ie 1/k. Defined in this way, it strictly only describes the useful life period of Fig 1, whereas mean life of an element includes a significant part of the wear out period as well and is sometimes taken as a measure of how long it takes for wear out to begin. If time is measured in intervals of Ø, the reliability function for a constant failure rate takes the form:

$$R = e^{-t/\phi} \tag{3}$$

This is shown in Fig 2.

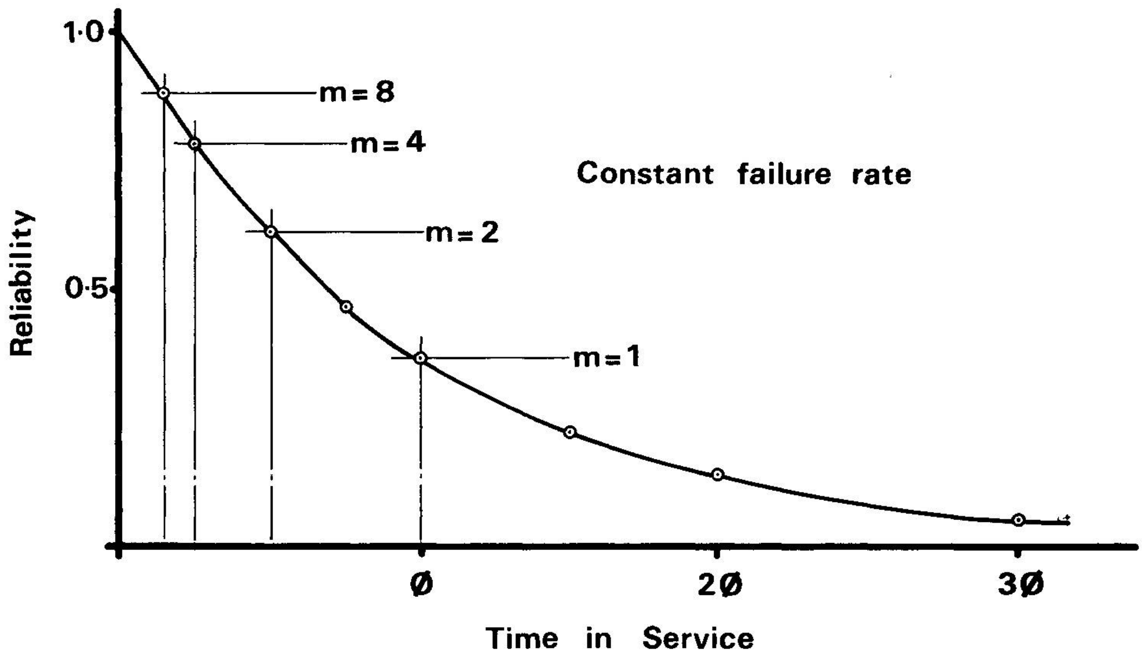

Fig. 2. Reliability and Failure Time

The probability of an element surviving to Ø is 0.37. The period between inspections might be selected as some fraction of Ø, (Ø/m), which gives an acceptable reliability, using the expression:

$$m = -1/\log_e R \tag{3}$$

If a probability of failure for a random failure mode is thus to be kept below 10%, at least ten inspections would need to be carried out during the mean time before failure. With only two inspections the corresponding probability of failure would be 39%.

The foregoing simplifying assumption of a constant rate of failure illustrates a general principle. In practice, the failure rate is likely to be variable and will be further complicated by the interaction between the failure of elements comprising a complete structural system such as a bridge. It is observed in fatigue behaviour that as the service time increases, the crack size increases and the residual strength decays, thus increasing the failure rate [6]. Furthermore, for the longer service lives in aggressive environments, fatigue failure rate will be influenced by degradation of the material due to other mechanisms, such as corrosion. As a general rule, it may be stated that inspections are going to be beneficial by truncating the tail of the statistical distribution of flaw size at the larger flaw end. The extent of the improvement in structural reliability and safety will depend on the quality of the inspection.

For redundant systems made up of many elements with a constant failure rate, the overall system failure rate will increase with time. If it is subjected to periodic inspection and consequent corrective maintenance, the failure rate may be taken as returning to zero after essential maintenance is done. An average failure rate may then be taken over several periods of inspection and this average approximates to a constant value. System reliability, measured in terms of mean times to failure, when plotted against the time between periodic inspections will then take the same form as Fig 2. Periodic inspection and maintenance will not improve the reliability of a system without redundancy, but it will improve the probability that an element or system that has failed will be restored to operational effectiveness within a given time.

2.2 Consequences of Failure and Unserviceability

The form and frequency of inspection will be influenced by the likely consequences of failure or unserviceability. A degree of unserviceability is more likely to be tolerated than is a high risk of collapse. If the latter is suspected, then usually the first reaction is to increase the frequency and intensity of inspection. In some cases this may provide the necessary assurance to preclude the need for further action.

It is the safety or reliability of the bridge as a complete structural system that is the ultimate concern of the owner and this is usually determined from the reliability of its components. Many system-component relationships exist, but probably the two main ones are the series and parallel relationships. In a series system, failure of any of the components results in failure of the system. An example would be the failure of the support or deck of a simply supported structure. The overall reliability of the series system will be the product of the reliabilities of its components. In the parallel system, the system does not fail when only one component fails. There is, therefore, a degree of redundancy which determines that a certain number of components must fail before the system fails. In such a system it is the product of the unreliabilities of the components which gives the system unreliability; unreliability being defined as unity minus reliability. An example of a parallel or redundant system is given by a multi-beam deck with a connecting composite slab. From the safety aspect, the system will only be redundant to the extent that certain beams might fail without reducing the global factor of safety below unity. Most bridges will be combinations of series and redundant systems and most of the redundancy will be active, that is, the components are in continuous service. When one component fails the conditions imposed on some other components become more onerous, thereby accelerating their failure rate. By identifying and repairing the failed component quickly in a redundant system a large increase in reliability can be achieved, since the system is only vulnerable during the time the component is damaged and under repair.

Some failures are partial, in that the bridge does not collapse, but it may be put out of service. An example would be the failure of the one bearing in a single bearing support. Such failures are usually readily apparent during any of the types of inspections listed previously. It is more problematical to determine trends towards partial or complete failure, but if sequential inspections and assessments give rise to suspicion, then they may initiate a process of derating or load restriction.

The severity of the consequences of a defect is one of the means that can be used in classifying defects. This has been done for steel and concrete structures by the Ministry of Transport in France [7] [8] [9], using the following categories:

B - Defects without important consequences apart from appearance.
C - Defects which indicate the risk of abnormal developments.
D - Defects which indicate developing deterioration.
E - Defects which show a change in structural behaviour and which may affect durability.
F - Defects which indicate the approach to a limit state, necessitating restrictions on use and rendering the structure unserviceable.

2.3 Resources for Inspection

The frequency and intensity of inspections will obviously depend on available resources in terms of manpower, its skills and the available equipment. In Europe there has been a long-established practice of recruiting inspectors from the more able group of craftsmen and tradesmen employed in the building and civil engineering industries. Only in this way could the number of people required with the necessary basic skills be obtained. Over the past decade there has been a requirement for added knowledge of basic theory and this is being met by in-house and extra-mural courses. Only in France has formal training in bridge inspection being undertaken on a national scale, but several countries have intensified their training method at regional level. Since inspection is closely allied to maintenance, the practice in a few countries is that bridge inspectors carry out minor maintenance not requiring equipment larger than hand tools. Greater involvement in repair work has usually been discouraged to preserve objectivity of inspection. With the growing relative importance of maintenance and inspection in highway operation and management, there is an expansion of knowledge in this subject area, which is giving it greater technical respectability. At the same time, bridge inspectors are acquiring a better status and self-confidence.

Technical equipment in support of the visual observations made during principal inspections has generally been confined to simple hand tools, gauges, markers, binoculars, mirrors, magnifying glasses, movement and crack width gauges. This is not so much due to restrictions on the purchase of more elegant and complex apparatus, as to the realisation that greater elegance, complexity and refinement does not improve the results of inspection to a degree which justifies the cost and effort involved. This is exemplified by the principle, "Inspect only as much and as accurately as is necessary", contained in the report of a Project Group set up by the German Federal Highway Institute [10]. For special inspections, more advanced diagnostic testing is necessary and justifiable, even to the extent of deploying techniques which are in the stage of research and development. The boundary between research and practice is fluid, so that some procedures that were research projects 10 and even 5 years ago are now close to application during principal inspections. Examples are the measurement of half cell potentials and resistivity in reinforced concrete for determining the risk of corrosion activity.

The means of access are an important aspect of inspection and are a resource which can strongly influence its quality and methodology. The neglect of maintenance considerations in the design of bridges over the past two or three decades is gradually being remedied, but it is going to be reflected for some time in the difficulty of getting access to the more vulnerable parts of bridges. Traditionally long steel bridges over estuaries and deep valleys have been recognised as being in need of regular inspection and maintenance and have been equipped with maintenance gantries. Some gantries have had operational deficiencies, and have presented a significant maintenance problem themselves. The hope that concrete bridges would be maintenance free has not been fulfilled and this has encouraged development of a range of access measures. The mobile hydraulic platform operating from the bridge deck is probably the most versatile and has been widely used in Germany, Italy and France. Average utilisation of such equipment is not high, however, ranging from 400 to 1100 hours per annum for each machine in 1975 [1]. Relatively heavy equipment may be needed to meet operational and safety requirements and it will occupy two lanes of a bridge deck. The overall weight of current machines is between 50 and 150 times the load carrying capacity of their platform, depending on reach. A further obstacle to their use is the increasing height of parapets and noise barriers demanding different forms of articulation and larger operating ranges. In Germany a third generation of this type of mobile bridge inspecting equipment is going into operation to overcome some of these problems. The railways have been dealing with them for many years and have given careful consideration to the design of special access machines to operate in both the upward and downward mode in the presence of overhead electrified lines [11].

In Britain the demand for such machines for highway work has not been great. This is probably because of a combination of several factors such as the absence of hilly terrain on major routes, the availability and adaptability of the simpler lifting hydraulic platforms for inspecting street furniture and some doubts about the cost effectiveness of the more versatile machines. However, the increasing cost of using scaffolding in some of the more difficult situations may cause some reconsideration of this aspect. Walkways are being looked upon with increasing favour, not only for the longer spans where they have been traditionally installed, but also for medium spans in inaccessible locations. When used as the supporting framework for demountable platforms made of standard prefabricated planks, they can provide a flexible system of access for both inspection and maintenance.

3. TYPES AND SEVERITY OF DEFECTS

There are a variety of ways of describing and classifying defects and the condition of the structure, all of them directed at making bridge inspections more comprehensive and uniform. One way is to group defects in terms of the main elements of the structure [1]. A considerable development on this is the illustrated catalogue format adopted in France [7] [8], in which the defects are broadly classified in terms of the type of structure and are then described in detail, with photographs and comments, and given an index of severity on the scale described in section 2.2 of this paper. A combination of a scale of severity of defects with a scale of their extent has been proposed by a Bridge Inspection Panel of the UK Department of Transport [12]. By a subjective integration of the rating of severity of defects on individual components, an assessment of the general condition of the structure is derived. It can be argued that using any scale or index calls for judgements on the likely consequences of defects that are beyond the capabilities of the inspector. Nevertheless any qualitative scale is likely to involve judgement to some degree. They do provide a framework for a rational approach and it is hoped that most of their shortcomings will be overcome by practical experience.

Smith [13] and Blockley [14] have examined the history of the more spectacular bridge collapses over the past century and have attempted a broad classification in terms of causes. It is of interest to note that in the sample of 143 cases examined by Smith, 113 occurred after two years in service and the causes may be broadly classified thus:

Flood and foundation movement (57% scour)	59%
Defective material or workmanship	14%
Overload or accident	11%
Earthquake	10%
Fatigue	4%
Corrosion	1%
Wind	1%

Blockley examined structural reliability theory in dealing with parameter uncertainty and its inadequacies in dealing with system uncertainty. He also discussed the effects of human errors and listed these as either deliberate or non-deliberate acts. Against this background he produced the following main categories of causes of failure which are design and construction orientated:

- Overloading and/or understrength
- Random hazards
- Oversight of basic mode of behaviour
- Errors in construction and communication
- Adverse financial, political or social climate
- Misuse or abuse

These categories are of interest, but they do not necessarily reflect the pattern that emerges from inspection of bridges before they fail and do not give a clear indication of how effective inspection might be in anticipating and preventing failure. Unfortunately, there are no statistics on this, so that the following discussion is largely speculative. In order to embrace serviceability, as well as collapse, failure is taken to mean unfitness of a structure or element for its purpose. Failure modes may be classified as either catastrophic failures or degradation failures.

- Catastrophic failures are both sudden and complete. A sudden failure is one which could not be anticipated by prior inspection and a complete failure results in the total cessation of function.
- Degradation failures are both gradual and partial and result in deviations from acceptable limits without complete cessation of function. They can be anticipated by prior examination.

It is difficult to restructure the above percentage classification of the data on complete failures collected by Smith, but assuming the failures due to flood and scour were sudden, catastrophic type failures account for about 80% and degradation type failures for only about 20%. This is not surprising in view of the fact that all the failures listed attracted considerable publicity in view of their catastrophic nature and, in many cases, were the subject of public enquiry. Many of them would not have been detected by prior inspection, even with modern equipment.

Periodic inspection can only anticipate failures of the degradation type, and it does so by revealing changes in defects. If design and construction are to become more maintenance orientated then in addition to making structures more accessible, there should be recognition of the limitations of inspection by having larger partial safety factors and higher quality for materials in locations where a catastrophic type of failure can occur or where the probability of detecting a partial failure is low before it becomes complete.

4. INSTRUMENTAL AIDS

In the present state of the art, periodic bridge inspection is done primarily by direct observation assisted occasionally by touching and listening. For the immediate future there seems to be no practical alternative to the combination of the trained eye and the experienced and perceptive mind, so that the role of instrumental aids will be a supporting and confirmatory one. The simple optical equipment referred to previously can enhance the power of visual observation and there is probably scope for the application of closed circuit television, with its image enhancement capability, to the detection of defects at a distance, above as well as below water. Monitoring on colour television of the image obtained by an endoscope or borescope in a confined location is a considerable improvement on the view through the normal eye piece with the added advantage of obtaining a video recording. However, it is possible to increase the sensitivity of detection methods to the point where the indication of flaws is either false or confusing. The author has attempted to examine fine crack patterns in a concrete surface with the use of a fluorescent dye. The dye was in the form of a powder of 10μm particle size suspended in a volatile liquid. After application to the surface the particles concentrate along the line of any cracks, wider than 10μm, and become visible in ultraviolet light. This technique provided some assistance in tracing the extremities of visible cracks, but it tended to cause confusion where crack patterns were ill-defined or where the concrete surface was rough. Most of the cracks revealed were characteristic of a normal concrete surface and had no structural significance.

Visual inspection has obvious limitations in terms of detecting internal and hidden flaws, in assessment of quality, in making remote observation, and in speed of response. Research is in progress to overcome some of these limitations and it is having some success, but at present it falls well short of providing the ideal diagnostic service the inspector and engineer would like to have.

Since inspection is primarily concerned with safety its ultimate goal is the determination of structural condition and strength. Strength, whether intrinsic or residual, is not directly measurable without causing unacceptable damage, so that all non-destructive methods rely on an indirect evaluation of strength by measuring some other quality, whose correlation with strength is determinable. Sometimes this correlation is tenuous and involves intermediate stages. For example, in the ultrasonic testing of concrete the transit time of 50kHz pulses through the concrete are measured to give the pulse velocity. This is directly related to the elastic modulus, density and Poisson's ratio, all of which have an indirect association with concrete strength. The exact nature of this association depends on the composition and quality of the concrete. To achieve an assessment of strength which is with ±25% of the actual value usually requires calibration of pulse velocity using cubes or cylinders of identical composition which can be strength tested. If the concrete contains reinforcement there are added complications because of the higher velocity of sound in steel.

Various methods of assessing concrete strength in existing structures are described in a recent British Standard [15] and a wider review of testing techniques for all the main materials in bridges was given in the OECD Report [1]. The latter also drew attention to particular problems where instrumental aid might be of assistance to inspection, indeed might be the only possible means of carrying out an inspection. One of the problems referred to was the state of fully bonded prestressing steel tendons in post-tensioned concrete. Some of the methods tried to solve this will be briefly described to illustrate some of the difficulties involved.

No direct non-destructive method of examining the condition of tendons embedded in a structural member has been developed hitherto. Radiography comes nearest in principle to achieving this, but under the conditions encountered in bridges it can provide little information on the degree of corrosion of the tendon or its loss of section. This is because the change in optical density on the radiograph is either too small or too limited in area to be detected. This is hardly surprising when it is realised that the radiation of X or gamma rays have to penetrate a thickness of concrete of 0.5m and more, with an exponential reduction in their intensity with thickness, and with a marked penumbral effect due to size of the radioactive source.

It is known from past experience that little or no corrosion of tendons occurs when the ducts in which they are placed are fully grouted with cementitious grout. The condition of the cable might, therefore, be inferred from the continuity and density of the grout. If no voids are present, then the tendon is assumed to be well protected whereas the presence of voids is taken as a potential corrosion risk. The lack of continuity of grout is more readily detectable on a radiograph than corrosion of steel, but in practice there are limitations. Because voids are more likely to occur in the upper part of a duct and because the surface between the grout and a void is approximately horizontal, the X rays or gamma rays should be directed horizontally to detect void boundaries. However, the image projected on to the radiograph will be masked by tendons and by metallic duct formers in the same plane. Nevertheless, it is possible to detect voids in ducts in narrow concrete webs and beams with no more than one duct in any horizontal plane.

To obtain detailed information on the state of the tendon and the grouting, it is necessary to resort to more destructive means [16]. 25mm holes have been drilled into a number of ducts on selected bridges in the UK, using as-built drawings to locate them. The ducts were carefully opened to avoid damage to the tendon and then inspected using a borescope. Where a void was present the state of the tendon could be examined. If possible samples of grout were removed for analysis. From 3 to 5 holes were drilled into each duct. Air was evacuated through each hole in turn and the pressure (degree of vacuum) measured at remaining holes. This gave an indication of continuity along the duct. The volume of any voids present was measured by connecting the evacuated holes to a water gauge consisting of a perspex tube dipped in water. The rate at which air could leak out of ducts was determined from the input flow rate of nitrogen gas applied to the holes at a pressure of $17N/mm^2$ above atmospheric pressure. Where high flow rates were measured, the points of leakage could be determined by the generation of bubbles in a soap solution applied externally to the structural member.

Voids were discussed in 55% of the ducts examined in 10 bridges. They were usually larger in older bridges and in diaphragms cast in-situ between beams. Voids tended to be concentrated at high points in the duct profile and were found most frequently where they were deflected upwards over supports in continuous structures. They may also be present near anchorages. In six of the bridges, voids were of sufficient size so as to reveal the tendons, but even so they were covered with a thin film of cement paste and there was no evidence of serious corrosion. The degree of protection would be inferior to that given in a fully grouted duct and will be at greater risk from carbonation and ingress of chloride ions. Thus the maintenance of protection may depend on how well the ducts are sealed.

Another method of assessing the integrity of the tendon and the anchorage is to determine the level of residual prestress at strategic locations in the concrete. Although more complex than observations on the condition of the tendon, it does relate directly to the most important structural effect and provides a direct indication of the loss of prestress. A method for measuring residual strength by partial stress release is being developed in France [17]. It involves cutting a thin slot in the surface of the concrete by circular saw and then inserting a thin flat jack into it. The pressure on the jack is increased to restore the strain across the slot to the level in the concrete before it was cut. The pressure at nil strain is then the initial stress. Tests done hitherto show a maximum difference of 10% between the measured stress and an applied stress. Difficulties may arise if the concrete at the surface has markedly different properties to that in the interior of the member, either due to the method of construction or the curing, weathering and ageing in service. They may be partly overcome by cutting slots to different depths. If reinforcement is present and it is cut some corrections have to be made for local redistribution of stress. The level of stress measured is the resultant value, from which stresses due to live, dead and environmental loads would have to be deducted to obtain a meaningful value of residual prestress. If, therefore, the residual value is relatively low there is the risk of large errors.

5. MONITORING OF BRIDGES

Techniques and equipment for monitoring the overall condition of a bridge present possibilities of making a rapid assessment of condition and changes in condition, and of detecting faults which might not be found by visual inspection. However, no method has yet been perfected which provides a practical and universal means of monitoring. The following are some techniques which have been suggested or are under development:

5.1 Changes in Geometry

A project group of the German Federal Highway Institute has reported on the monitoring of bridges [10] and proposals are made for the measurement of geometric changes as a means of detecting faults in the structure. Various methods of measuring are proposed including conventional geodetic techniques, hydrostatic levelling, electronic range measurements, laser measurements, photogrammetry and electrical and mechanical measurements. The procedure requires that a reference state for the bridge be established initially and limit values prescribed for various inspection measurements to be made. Selected main checks are first made and only if these show results outside the limit values are the full set of detailed supplementary measurements made. The methods of measurement proposed appear to be most applicable to medium and long span bridges where the geometric changes are likely to be large enough to be measured with sufficient accuracy. Most of the current problems with short span concrete and composite structures are such that, even where there is substantial development of a flaw or loss of material, the resulting geometric changes are small and difficult to distinguish from thermal effects.

5.2 Changes in Response to Vibration

The objective is to relate defects in the structure to changes in dynamic characteristics. The development of a technique using traffic and wind-induced vibration has been described by McKenzie and Macdonald [13]. It consists of temporarily attaching accelerometers to the structure and making simultaneous recordings of the vibrations. The modes of vibration and damping may then be determined by computer analysis and this provides a signature of the structure which will change only if the properties of the structure and its supports are changed.

In the SHRIMP method developed by Savage and Hewlett [19], a variable frequency sinusoidal force is applied to a point in the structure and responses at other points are measured. These responses depend mainly on fixity and stiffness of connections to other parts of the structure. Both the above vibration methods measure loss of stiffness, not loss of strength. A loss of stiffness implies a loss of strength, but a serious loss of strength could occur, as with a crack in a steel member, before producing a measurable loss of stiffness.

5.3 Acoustic Emission

This technique can detect and locate cracks by the sound produced during their development. Continuous recording is therefore needed and this makes it suitable only for vitally important parts of the structure such as the main cables in a suspension bridge. It has also been used in an endeavour to detect cracks during loading tests on a damaged reinforced concrete structure and during repairs to a post-tensioned concrete anchorage. In both the latter cases the results were disappointing and no clear pattern of crack development or of a relationship between emission and scale of cracking could be identified.

5.4 Support Reactions

Diruy [20] and Chatelain [21] have described the development of an instrumented bridge bearing for measuring the redistribution of reactions under prestressed concrete bridges. Measurements made over a period of 5 years showed the effects of creep and shrinkage but superimposed upon this are variations due to thermal changes. It is not known whether the results would give a definite indication of loss of stress in the structure due to corrosion of tendons. The specially designed bearings have to be installed during the construction of the bridge. Other commercially produced instrumented bearings are available but the development of load-measuring techniques without special bearings would simplify the use of this method of monitoring. The monitoring of support reactions would provide a valuable indicator of changing conditions in continuous structures.

5.5 Corrosion Monitoring

The risk of corrosion of reinforcement and prestressing tendons may be assessed by installing electrical resistance probes [22] during construction of the bridge. The probes consist of exposed and protected thin metal electrode and, as the former corrodes, the electrical resistance of the probe changes. To obtain representative results, probes should be placed at a number of points within the structure and it may be necessary to ground the probes to the tendons.

The techniques described in sections 5.4 and 5.5 above require the installation of instruments in a structure and this can sometimes only be done during construction. It follows that, if condition monitoring is to make a significant contribution to bridge inspection, the techniques and equipment have to be carefully considered during design.

6. ECONOMICS OF INSPECTION

Attempts were made to compile costs of bridge inspection and maintenance in the reports of the OECD [1][9]. Firm data was difficult to obtain because most highway organisations did not identify them as separate items. Various estimates showed that in 1974 the annual cost of inspection ranged from \$13 to \$130 per bridge. The low cost figures probably referred to superficial inspections of small structures. Ratios may be more meaningful. For example, the ratio of annual inspection cost to current construction cost, both expressed in terms of unit area of bridge deck, varied from 2×10^{-4} to 7×10^{-4}. The annual maintenance cost expressed as a ratio of current construction cost ranges from 0.3×10^{-2} to 1.5×10^{-2}. Combining the two gives a ratio of inspection cost to maintenance cost in the range of 1.5% to 20%. In many European countries maintenance cost of bridges has multiplied 3 or 4 times in the past 5 years reflecting not only a growing rate of deterioration, but also, hopefully, the increased effectiveness of inspection.

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Bridge Inventory and Inspection Programs in New York State

Inventaire des ponts et programme d'inspection dans l'Etat de New York

Zustandsaufnahme und Überwachungsprogramm der Brücken im Staat New York

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SUMMARY
Bridge inspection is an accepted and necessary part of the activities required to assure bridge safety. Records produced as a part of a bridge inspection program may be supplemented with other data and be used for a variety of bridge program management purposes. Because of the competition for construction funds, it is important that transportation system managers have the means to identify problems and costeffective solutions, and have the ability to allocate funds in such a way as to produce the best possible transportation system at the least cost. This paper reviews the type of records which are of value for this purpose and the way in which the information is obtained and used to produce the desired result.

RESUME
L'inspection des ponts fait partie des activités nécessaires à la sécurité de ces ouvrages. Des protocoles de mesures effectuées dans le cadre d'un programme d'inspection peuvent être complétés par d'autres données utiles et être utilisés pour des programmes de gestion de ponts. Eu égard aux fonds limités, il est important que les responsables puissent identifier les problèmes et leurs solutions afin d'attribuer les fonds de façon à produire le meilleur système de transport pour les frais minima. Ce rapport présente le genre de mesures à effectuer et la façon de les réaliser.

ZUSAMMENFASSUNG
Die Brückenüberwachung ist eine allgemeine akzeptierte und notwendige Tätigkeit, um die Sicherheit von Brücken zu garantieren. Protokolle, die als Teil eines Brückenüberwachungsprogrammes erstellt werden, können mit zusätzlichen Daten ergänzt und für den Ablauf verschiedener Brückenbauprogramme benützt werden. Wegen der Nachfrage für Baukapitalien ist es wichtig, dass die Verantwortlichen die Mittel haben, Probleme und kosteneffektive Lösungen zu erkennen, und dass sie die Fähigkeit besitzen, Kapital so zuzuteilen, dass ein bestmögliches Transportsystem zu geringsten Kosten geschaffen wird. Dieser Beitrag behandelt die Art von Protokollen, die zu diesem Zweck von Wert sind und zeigt, wie diese Information zustande kam und verwendet wird, um die gewünschten Resultate zu erzielen.

This symposium is devoted to the maintenance, repair and rehabilitation of bridges. Just as any properly engineered bridge must have an adequate foundation, planning for bridge maintenance, repair, rehabilitation and replacement must also have an adequate foundation. That foundation is provided by the development of a bridge data file, the gathering of bridge information for the data file and the use of the data to identify what should be done to the bridges in the inventory, and when.

Because the funds required for the correction of bridge problems have never been sufficient to meet all needs, and probably never will be, it is important for a bridge owner to identify problems and cost-effective solutions, and to have the ability to allocate funds in such a way that the transportation system containing the bridges is allowed to operate at the greatest possible efficiency. This can be done with accurate and current bridge inventory and inspection records, and the means to analyze the records.

This paper will discuss what should be included in a bridge data file, how the information should be obtained, how the information should be managed and how the information can be used. The experience of the New York State Department of Transportation will be used to illustrate the accomplishment of these activities.

First, some definitions will be useful. A bridge data file is made up of two elements, information about the bridge which does not change with time, defined as inventory data, and information about the bridge which does change with time, defined as inspection data. Inventory data is constant; inspection data varies with the bridge condition.

THE CONTENTS OF THE FILE

The first and most important consideration when developing a bridge data file is the contents of the file. The number and type of items which go into making up an inventory file and an inspection file can vary widely depending on the purposes for which the file is to be used. Those creating the file must first decide what these uses will be.

The minimum content for files maintained in the United States is found in the "Recording and Coding Guide for the Structures Inventory and Appraisal of the Nation's Bridges". This is a 40 page manual published by the Federal Highway Administration (FHWA) and endorsed by the Subcommittee for Bridges and Structures of the American Association of State Highway and Transportation Officials (AASHTO). It identifies and describes 57 inventory items, 16 inspection and appraisal items and, if the bridge is to be rehabilitated or replaced, 16 items relating to the proposed improvement.

The inventory items include 16 items relating to bridge identification, location and jurisdictional information and 31 items relating to bridge type, dimension and geometric information.

The inspection or condition related items include an evaluation of the deck, superstructure, substructure, stream channel and bridge protection and retaining walls, if any. These items are rated on a scale of 0 to 9, with zero being the poorest condition and nine the best. Three other items are found in the inspection group, two providing the load capacity of the bridge and the third an estimate of the remaining life of the bridge.

The appraisal items are intended to evaluate a bridge with relation to the highway system it serves, and include numerical rating values for the general condition of the bridge, the relationship of the bridge to the approach highway width, the adequacy of the vertical and horizontal underclearances, the safe load capacity, the waterway adequacy and the adequacy of the alignment of the approach roadway.

The items related to future improvements provide the basic information required for establishing the criteria for a bridge replacement, should one be judged necessary. These include the proposed bridge length, width and loading requirements; the date when the new bridge should be completed and the estimated cost of the bridge.

These inventory, inspection and appraisal items make up the minimum data which must be reported to the FHWA for each public bridge in the country, each year. The requirement for this is found in Federal statutes and the data collected is used to provide a continuing national perspective on bridge conditions and a means to allocate Federal aid for bridge rehabilitation and replacement among the states.

Many states have established inventory and inspection programs which only gather this data. Others, including New York, have gone beyond these requirements in order to build a file which has far greater use. The incremental extra cost of gathering the additional information was small, so the additional benefits derived from the larger file were obtained with little extra expence.

In New York the content of the file was developed in 1970 with a series of discussions involving all potential file users, aimed at identifying all information which might possibly have any value for any purpose. The uses of the file identified at that time included the ability to assure bridge safety, to prepare bridge maintenance work programs and bridge construction programs, including prioritizing of projects; to assist with short and long-range capital budget planning; to evaluate load capacities of bridges; to assist with the routing of overloads; and to evaluate new structure types and details.

This effort resulted in the establishment, by 1972, of a bridge data file consisting of 194 inventory items and 60 inspection items. In 1978 a number of additional items were added which were required for the Department's bridge load rating program. These items are kept in a separate file, called the bridge load rating file, but the type of data is either inventory (fixed) or inspection (condition variable).

The New York State inventory, inspection and load rating data files are computerized and the data is stored in the Department's computer center in Albany. A new inventory and inspection data management system went into use on July 1, 1982 and all file data was converted to the new system at that time. Because the development of the new system incorporated data base management concepts, in which inquiry is made directly to the data source rather than through a sort process, inquiry response time has been greatly reduced from that required for the old data management system. This permits on-line inquiry, and allows the use of remote cathode ray tube terminals in the Regional Offices of the Department. This development also allows the scrapping of vast amounts of paper; the hard copy output from the data file.

The New York State inventory file includes 55 items of bridge identification, location and jurisdictional information; 68 items of bridge type, dimension and geometric information; 27 items of bridge detail and hardware information, such as railing types, curb types, drainage and lighting; 9 appraisal items; 12 items required for planning future improvements and 21 items relating to the underpassing roadway, if any. The significant differences between the minimum inventory described earlier and the New York State inventory are that the New York inventory records each span of a bridge rather than the bridge as whole, providing important detail; records ramps which meet or leave bridges as separate bridges, a useful feature in complex interchanges; includes bridge detail and hardware information and uses more questions to gather certain information so that the information can be more specific and thus more useful.

The inspection portion of the New York State bridge data file includes condition information on abutments, wingwalls, stream channel, bridge approaches, deck elements, superstructure, piers and utilities, with the condition of 50 items spread across these eight categories and recorded on a per span basis at the time of each inspection. In addition, each of the eight bridge elements noted above are given a condition rating, and the bridge itself is given a condition rating. New York State rates bridge conditions using a scale of 1 through 7, with 1 the worst and 7 the best. Finally, the inspection includes nine items related to repairs which are found to be necessary as a result of the inspection, and the quantities of material or work required to make the repairs.

The bridge rating portion of the file, created six years after the inventory and inspection portion, contains additional, more detailed inventory information about the structural system and deck of the bridge and additional information about the level of deterioration of the critical parts of the bridge.

In New York State bridges are also documented in a manual file, called the bridge history file. This is done to provide a means of capturing and retaining, in one place, important information which is not readily kept in a computer file, in addition to copies of the input data for the computer file. The bridge history file is intended to complement the computerized data file so that an immediate response can be provided to most questions relating to a specific bridge by reviewing both information sources. The contents of the bridge history file include:

Photographs showing
- both approaches to the bridge
- the bridge roadway
- the bridge in elevation (from both sides for a stream bridge)
- the configuration of abutments, wingwalls and piers
- a general view of the underside of the bridge
- problem areas, if any
- the bridge identification number

A statement indicating where the bridge plans are located, or preferably a set of plans, if the plans are not preserved on microfilm.

Foundation construction information, including pile driving records and foundation design loads.

Other construction information which might have future value.

Hydraulic design information, if a stream bridge.

Bridge inventory, inspection and load rating input forms.

Other information may be included, if it is needed to provide the quick response capability. The bridge history file is maintained by the Department's staff in the Regional Office having jurisdiction over the bridge.

The forgoing discussion related to the content of the bridge data file, and the considerations which must go into developing that content. Following the establishment of the content the major work effort of a bridge data program must take place - the gathering of the information for the file.

THE GATHERING OF THE INFORMATION

Here, as with all engineering activities, the most important concern must be control of quality. The best-conceived data file will be of little or no value unless the material in it is creditable. The data must be gathered by personnel who understand what a bridge is and how it functions, and who are well trained in the use of the data storage system and the forms used for inputing that system.

The personnel should be engineering professionals, or technicians with many years of bridge related experience. They must be well-motivated and conscientious, since they will be working without direct supervision. Their training must include strong emphasis on the interpretation of condition data, which makes up a significant part of the file and is subjective. The work must be monitored on a continuous basis so that problems are solved early and not allowed to continue or grow. And the work should be subjected to extensive editing and proof checks, not because of lack of confidence in the workers, but simply to assure that the best information possible goes into the file. Edit checks may be used to normalize the information which, despite training, might vary because many people are likely to be involved in the data gathering.

For efficiency in data gathering, inventory information should be obtained from existing paper records whenever possible. Doing so reduces the field time required for the work, and allows work to continue during periods of bad weather. Data taken from paper records should be verified during field visits to the bridge since there can be changes during construction which do not show up on record plans, and work done by maintenance forces during the life of the bridge which has not been documented.

New York State Bridge data has been gathered in a variety of ways. A pre-1970 data file, with a small amount of information about the more than 6000 bridges owned by the state, was converted to the present system using a computer to make the transfer. The result was printed with blanks shown where data required for the new file was missing. This output was sent to the Department's Regional Offices with instructions to verify the information in the file, and gather the missing data. This work continued for several years. In addition, the file was subjected to an intensive edit prior to the recent changeover to the new data-base management system mentioned earlier.

Inspection data for state bridges is gathered on a regular basis by state personnel assigned to the maintenance program of the Department. The inspectors receive training annually in order to sharpen their skills, inform them of new types of bridge problems, make them aware of inspection deficiencies noted in the previous year and generally make them understand what is needed to make quality inspections. Rating data for state bridges has been and continues to be gathered by the Regional Office staff. This work has not progressed as rapidly as desirable, but will be completed in the next year or two.

Data relating to the remaining publicly owned bridges in New York State are documented in the bridge data file as well. This includes more than 11,000 County, Town, Village and City bridges, as well as those owned by authorities. The information for virtually all of these bridges was obtained by consulting engineers working under the direction of the Department, as a result of an action by the New York State Legislature of 1977. The continuing inspection of these bridges is also being done by consulting engineers, but at a slower pace than desirable because of competition for limited funds.

THE MANAGEMENT OF THE INFORMATION

After the content of the data file is established, and the information for the file obtained, the file must be maintained. The management of the file includes three important elements. The first is to assure that the file contains all the data required for bridge decisions, the second is to have the data accessible, and the third is to have the data creditable. Fundamental to all aspects of managing the data file is the need for a responsive computer system designed to serve the system user. The requirements for the computer system should include security for the data and the ability to readily recover and manipulate the data. The data itself has no value; its only value is its availability for use.

In New York these requirements have been met. The first was accomplished by devoting a great amount of time in determining the specific items to be included in the file, as discussed earlier. The test of success for this requirement is that practically no change has had to be made in the file in the 10 years it has been in use. The second requirement, accessibility, was met with the recent conversion of the file to a data base system. This system will allow on-line access to the file for individual bridge inquiries. The third requirement, credibility, was met by controlling the information going into the file. Data can only be added to or deleted from the file by the Inventory and Inspection Unit of the Department. Thus, all data is screened by the same two or three people, providing a high level of consistency. In addition, edit checks are constantly being run to seek out problems with the data. Finally, a continuing program of file updating is required to reflect changes in bridges brought about by replacement, rehabilitation and maintenance programs.

THE USE OF THE INFORMATION

The development and management of a bridge data file will take much time and effort. The benefits of an expanded, well maintained file to New York State were cited earlier, and are as follows: the ability to assure bridge safety; to prepare bridge maintenance work programs and bridge capital construction programs, including prioritizing of projects; to assist with short and long range capital budget planning; to evaluate load capacities of bridges; to assist with the routing of overloads; and to evaluate new structure types and details. These benefits are discussed in detail below.

Assurance of Bridge Safety - A key element of any bridge inventory and inspection system is the regular inspection of bridges. AASHTO and FHWA have established an inspection cycle of two years or less. The inspection made for this purpose is a survey of bridge condition and is not done in the detail required for a refined structural analysis or the preparation of plans for a rehabilitation project. In New York State the general inspection of a 100 foot bridge will take a two person team about two hours, under average conditions.

General inspections must be made in order to monitor the condition of a bridge as it changes with time, and to find deterioration which may make the bridge unsafe. Without inspections unsafe conditions are likely to go undetected and cause serious damage to the bridge, or collapse with resultant danger to the user.

Preparation of a Bridge Maintenance Work Program - The New York State bridge inspection form includes nine items, with quantity estimates, which are used by the Department's Maintenance Division to plan remedial work on bridges needing such work. This information is taken from the inspection forms for those bridges which are to be included in the bridge maintenance work program. The quantities are summarized and labor and equipment factors added, providing the Division with the information needed to budget for bridge maintenance activities. The budgeting data, coupled with a review of rate of deterioration of the part of the bridge requiring attention in order to provide a time frame for the work, provides the information needed for planning a bridge maintenance work program.

Preparation of a Bridge Capital Construction Program - As a part of the inspection of New York bridges each component of the bridge is given a numeric rating value based on condition. The condition rating for the bridge as a whole is developed by weighting bridge components in proportion to their importance for the proper structural functioning of the bridge. For example, primary members are given a weight of 10, secondary members 5 and sidewalks 2. The component and the component weight are multiplied, all weighted components are summed, and a weighted average value computed providing the condition rating for the bridge. In a variation more commonly used, a traffic factor is applied to the condition rating to produce a combined value. The traffic factor provides an indication of the relative importance of the bridge, with higher traffic volumes indicating greater importance. The result is a priority rating for the bridge which is typically used for programming in New York State

It is likely that other states use similar methods to develop priorities. There is a national method which was developed by AASHTO and is shown in the "Recording and Coding Guide" mentioned earlier. It uses bridge condition for 55% of the final value, geometric conditions and traffic for 30% of the final value and detour length and traffic for the last 15% of the final value. These items are combined to calculate the "Bridge Sufficiency Rating," which is used by the FHWA to show nationwide bridge priorities and as a basis for all ocation of federal funds to the states for bridge rehabilitation and replacement. The data used to calculate this rating are provided by the States annually, and are that data discussed earlier as being the minimum which a State must obtain for the inventory and inspection file. New York State continues to use the state priority method for decision making, primarily because it has been in use longer than the Federal and the longer data base is valuable for progress reporting and projections. The two systems correlate generally, and no program management problems have been experienced because of the use of the dual system.

Short and Long Range Capital Budget Planning - With the development of a reliable computerized bridge data file and the addition to it of a continuous flow of inspection data showing changes in bridge condition, it is possible to develop computer-based analyses showing condition trends. With the use of defined condition levels indicating the need for rehabilitation or replacement of bridges, it is possible to develop projections of the numbers of bridges requiring attention at any given time. Adding cost-to-correct values, estimates can be made of the expenditure per year, or other interval, required to keep the average condition of all bridges constant or to improve such condition. Optimization studies can be made leading to the determination of the most cost-effective time to repair or replace specific bridges. In New York a computer model has been developed which will do this. The early results from this study are found in a report titled FHWA. N.Y./S.R. 80-70 "The Deterioration of New York State Highway Structures", and have been reported at the Transportation Research Board annual meetings and AASHTO meetings.

Evaluation of Load Capacities of Bridges - The load-carrying ability of a bridge can be readily determined if the data file information is complete enough. In New York State, the load rating portion of the inventory and inspection data was established to provide the raw material for this purpose. The computation is done using a computerized bridge load rating program. The output, while not sufficiently refined to be the basis for bridge load posting, does provide a variety of benefits. For example, the load rating value can be used as a second prioritizing method, in addition to the condition value. If used in this way, bridges with lesser load carrying ability would have a higher priority for repair, strengthening or replacement than those with greater load carrying ability. Bridges can be identified which represent the limiting load on a portion of a highway, and those identified upgraded so that the portion of the highway is made reasonably uniform in terms of the load-carrying ability of the bridges. Perhaps most important, a review of bridge ratings can be used to identify bridges which, while in good condition, were not designed for current loadings. Such bridges would never show up in condition-related deficient bridge lists, but are as great a problem to the highway user as those bridges which do.

Overload Routing - The routing of overload vehicles is facilitated by having data file information available for bridges along the proposed route. The ability of each bridge on a route to carry the anticipated load can be determined quickly using the bridge load rating computer program and, generally, without the need for a field reconnaissance. In some cases bridges may be found which are marginal in ability to carry the load. A field investigation will then be required to assure that their condition is no worse than that shown on the latest inspection report. In addition, such bridges may require a more thorough analysis than provided by the rating program. If a bridge on the proposed route is clearly unable to carry the anticipated load, an alternate route can be sought and evaluated quickly. These procedures allow responsive review of overload movement requests with minimal expenditure of money; and result in greater assurance of the safety of the bridges on the overload route.

Evaluation of New Structure Types and Details - With inventory and inspection data in sufficient detail, the performance of various structure types and details can be monitored on a continuing basis. Differences in performance can be determined between similar items, and performance related to time can be developed to show rates of deterioration of details, materials or construction methods. Generally, the level of detail needed to do this is not found in most inventory files, but if the file is developed in such a way as to allow the addition of items as new evaluation needs are identified, data bases can be started for these items.

Summary and Conclusion - Many states have an extensive bridge data file, while others have files designed to provide only the data required for FHWA. There is no best answer; each state must decide for itself how it will approach this matter. The New York Department of Transportation believes the decision to create a large file was the correct one because of the many benefits which have already been experienced and the continued and expanded usefulness of such a file in the future.

Bridge inventories need to be kept current, reflecting changes in bridges and the replacement of existing bridges with new. The data on file must be constantly checked for reliability. Inventories may have to be expanded to meet changing bridge technology or the demand for new kinds of bridge data.

Bridge inspections must be made as cost effective as possible. Inspection frequencies may be lengthened for certain types of bridges and shortened for other types. Inspection effort must be constantly monitored to assure that the result is consistant with needs.

Finally, the inventory and inspection records must be stored in such a way as to be readily recoverable and usable. Bridge inventory and inspection is not an end, but instead a means to provide safe, serviceable and economical bridges for the user.

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Inspection of Tokyo Elevated Expressway Bridges against Earthquake

Surveillance du réseau routier urbain surélevé de Tokyo en vue de séismes

Untersuchung und Unterhaltung von Hochstrassen in Tokio unter Berücksichtigung von Erdbeben

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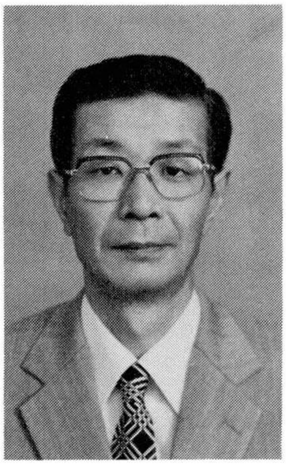


Tsutomu Komura, born in 1935, graduated from the University of Hokkaido at Sapporo, in 1958, and joined the Kanagawa Government from 1958 to 1960. For 22 years he has been contributing at the MEPC to designing, constructing and maintaining the bridges in the Tokyo metropolitan area.

SUMMARY
The Tokyo metropolitan expressways are toll highways which form a network in Tokyo and are composed mostly of elevated bridges. The Corporation perseveres in an effort to keep them in a favorable condition. Moreover, Tokyo is subject to so frequent earthquakes that the preparedness and measures against them have been provided for in the expressways. The inspection and maintenance work will be discussed in this paper emphasizing the measures against earthquakes.

RESUME
Le réseau autoroutier urbain à Tokyo est construit principalement sur des viaducs, que la Compagnie publique des autoroutes métropolitaines s'efforce de maintenir en bon état. Pour tenir compte des conditions propres à la région où des tremblements de terre surviennent souvent, des mesures anti-sismiques préventives ont été prises pour les autoroutes. Le rapport fait le point sur la surveillance et les travaux d'entretien entrepris dans le cadre des mesures de prévention des tremblements de terre.

ZUSAMMENFASSUNG
Die Tokio Metropolitan Expressways sind gebührenpflichtige Stadtautobahnen und bestehen zum grossen Teil aus Hochstrassen. Das Autobahnamt unternimmt viel, um sie gut zu unterhalten. Da sich in Tokio häufig Erdbeben ereignen, sind verschiedene Vorbereitungen und Massnahmen bezüglich der Hochstrassen getroffen worden. Dieser Beitrag behandelt Inspektion und Unterhaltung von Brückenbauwerken unter Berücksichtigung von Erdbebenereignissen.

1. OUTLINE OF THE TOKYO METROPOLITAN EXPRESSWAYS

It was the most important for Japan in 1950s to improve the condition of roads and to alleviate traffic congestion. Under such a condition, the "Law on Urgent Measures for Road Improvement" was promulgated in March, 1958. Since the traffic condition in Tokyo was the worst in those days, in line with these government measures, the Metropolitan Expressway Public Corporation (MEPC) was established on June 17, 1959, based on the "Metropolitan Expressway Public Corporation Law" to further the improvement of roads in central Tokyo and its vicinity.

The Tokyo metropolitan expressways are toll highways which form a network in the Tokyo metropolitan area. They are solely express traffic, are separated from business streets and have no level crossings. The main object of them is to smooth traffic for relatively short distance in the Tokyo metropolitan area.

The first expressway was opened on December 20, 1962. Later, the expressways were constructed and scheduled to be extended one after another not only in central Tokyo but also in nearby Kanagawa, Saitama and Chiba prefectures. At present, the expressways total 152.5 kilometers comprising 21 routes. The total number of automobiles using them up to the present has reached about three billion, and the expressways are now used by about 800,000 vehicles daily. In a section, 150,000 vehicles are counted as the highest volume in both directions in a day. Moreover, the expressways under construction are 10 routes with 67 kilometers in length, and new routes under study are over 100 kilometers. This state of the Tokyo metropolitan expressways is shown in Fig 1.

Tremendous sums of money are needed to execute such a big construction work of the expressways and to maintain them. Main financial resources are given through the flotation of the Tokyo metropolitan expressway bonds. These bonds should be redeemed over certain periods (usually thirty years) through collection of tolls after service to the traffic. Now daily receipts from the expressways are over 260 million yen.

The structures of the expressways are designed based on the "Road Structure Ordinance". Most sections of the expressways have two lanes in each direction, and are designed for a design speed of 60 km/h. The Bay-shore route and some of suburban sections are designed for a design speed of 80 km/h, having three lanes or two lanes respectively.

The expressways can be classified by structures as shown in Fig 2. The urban areas in a big city are generally crowded buildings, stores and houses, and land price is very expensive. In acquiring land for the expressways, the Corporation avoids privately owned land as far as possible, using public land instead, such as existing streets, rivers and reclaimed areas. The most part of the expressways are built on the existing streets. That is why the elevated expressway system is adopted, and the expressways may be considered as a series of bridges. A typical section of them is shown in Fig 3.

The Tokyo metropolitan expressways play a very important role in the transportation system of the Tokyo metropolitan area. For this assignments, road structures of the expressways should be always kept in a favorable condition. But their full volume of traffic does not permit partial daytime closure. Maintenance work is therefore done mostly by closing one lane late at night and in the early morning when traffic volume is less. The Corporation has developed a maintenance system which expends as much as seventeen billion yen a year on maintenance, repair, rehabilitation and upgrading of the expressways, mainly bridge structures.

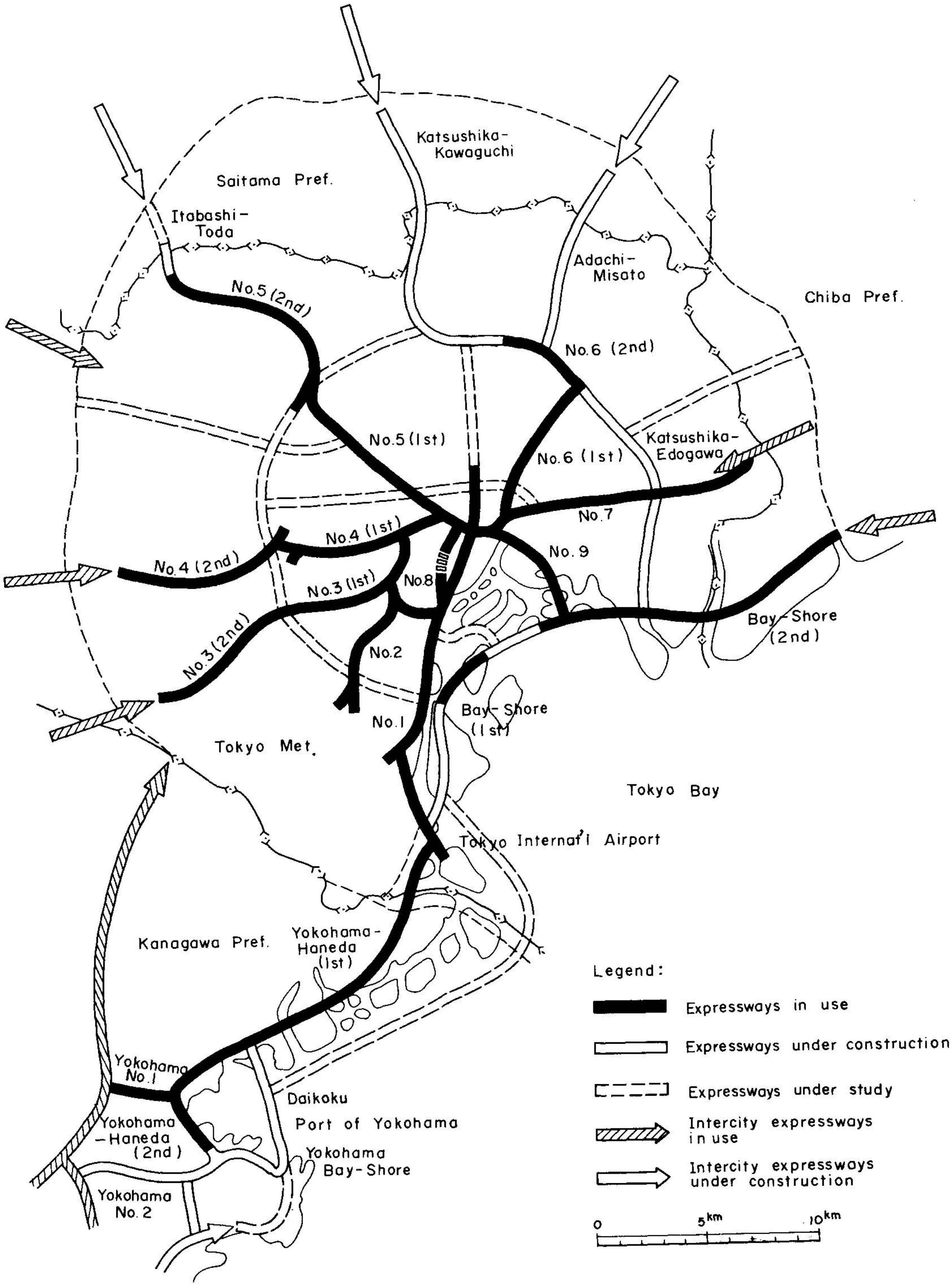


Fig 1 Network of the Tokyo metropolitan expressways

The bridge structures of the expressways are built to withstand earthquakes of considerable magnitude as strong as the Kanto Earthquake of 1923. As a further safe measure, addition to the above maintenance work, the upgrading work of the bridges against earthquake is carried out following various inspections.

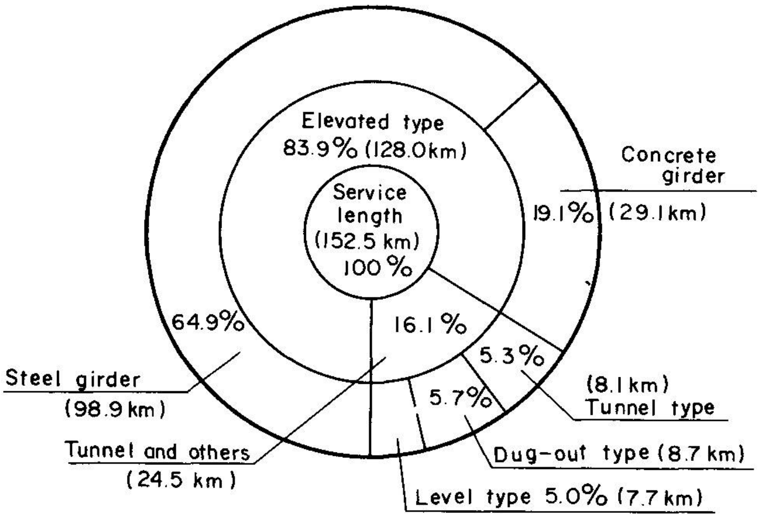


Fig 2 Structural types of the expressways

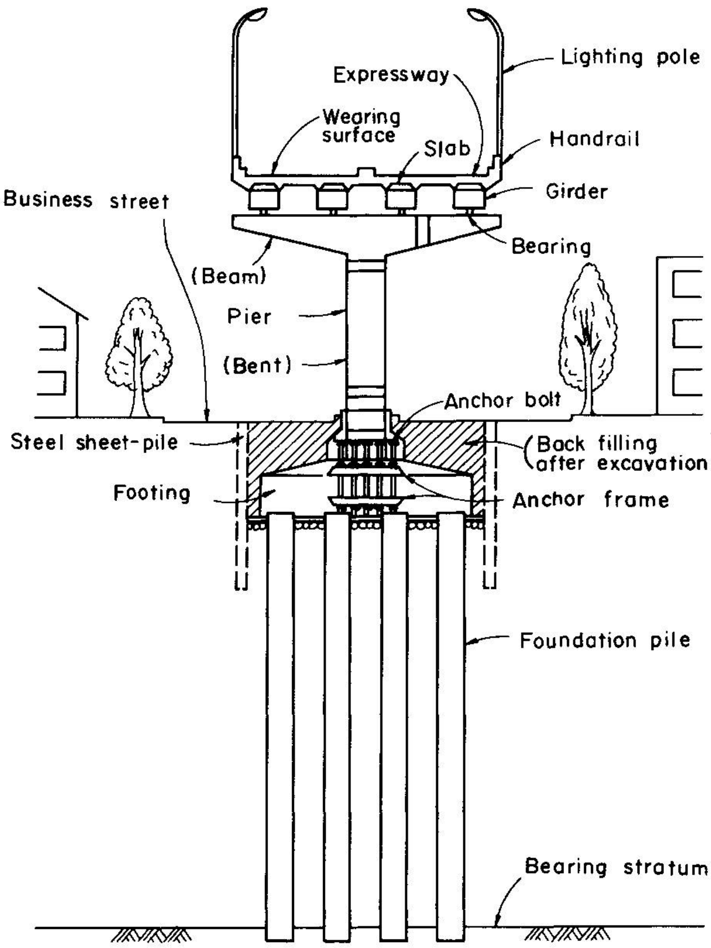


Fig 3 Typical section of the expressways

2. INSPECTION AND MAINTENANCE OF THE BRIDGES ON THE EXPRESSWAYS

2.1 Routine maintenance work

Main works of the maintenance of the Tokyo metropolitan expressways at earlier stage were to clean the road surface daily, to change bulbs of lighting poles, to upkeep the capacity of the road facilities and to restore the road structures damaged due to collison by motor vehicles.

After some years, primary maintenance works were added to them. They were repainting or coating of steel girders and piers, repair of wearing surface, disposal of water leakages, exchange of expansion joints damaged due to accumlated traffic volume and so on. In addition, due to the superannuation of structures, the increase of traffic volume and the increase of the large sized vehicles, the necessity of repairs of the bridge structures was increasing. Under such a condition, reinforced concrete deck slab has extensively deteriorated. The concrete slabs were strengthened a new stringer between two existing girders or pouring epoxy resin into crack. Its work continues still now. And the concrete girders or piers were also found to crack. They were rehabilitated by various methods.

Availing of the Niigata Earthquake of 1964 and the San Fernando Earthquake of 1971, anti-quake measures for designing were reviewed. It became the important work to provide the devices for preventing superstructures from falling down during earthquake as mentioned in Chapter 5.

Year by year, the increase of traffic volume on the expressways has kept traffic flow worse. To insure an adequate flow of traffic under this condition, the Corporation conducted various measures for traffic control; i.e. to increase emergency parking bays on the expressways and sloping access exit ramps, to widen the width of the expressways, to adjust traffic volume by lane control at merging zones on the expressways, etc.

Recently it becomes necessary to pay an attention to such environmental hazards of motor traffic as noise and vibration. To solve these problems, the Corporation installs appropriate facilities such as noise barriers on the handrails along the residential areas. With regard to vibration, surface pavement and expansion joints are improved. The exchange of deteriorated expansion joints is also effective against noise. As mentioned before, most of repair works are done at night. Noise of the works becomes a problem. The works are desirable to be finished before general bedtime or to be done without noise. The Corporation is developing the execution method or machine with little noise or without noise.

Many underground facilities which maintain the city functions rush in the roads because of less public space in a big city, and the number of them is extraordinarily large in Tokyo. They are subrailways, water and gas mains, telephone cables, high-voltage power transmission lanes and sewerage pipes. As the expressways extend in service length, they often become constructed close to the expressways. To protect the structures of the expressways in these cases is the important work.

It snows rare in Tokyo. But the road surface of the expressways is easy to get freez on snowy weather because they do not have the subterranean heat due to their elevated type of structures. It is difficult to remove snow or to scatter de-icing salts quickly because the expressways extend radially to suburb with no detour, moreover have congestion in entrances. Then an effective method for it is developed.

Fortunately, the serious defects concerning structures such as girders and piers have been rarely observed in the expressways. But the expressways more than 100 kilometers are ten years old in service, and they will have any defects due to the superannuation of structures under severe conditions. The Corporation is developing easier, more advanced and effective maintenance method. The main maintenance works for the structures of the expressways are as follows;

*Maintenance -- Scavengery (road surface, guide sign, pier, etc)
-- Inspection (structure, road surface, road facility, etc)
*Repair -- Repair (wearing surface, expansion joint, paint, downspout, guide sign, etc)
-- Rehabilitation (girder, pier, bearing, foundation, deck slab, handrail, etc)
*Upgrading -- (noise barrier, fall-proof device, emergency exit, emergency parking bay, etc)

2.2 Inspection works

The inspection work of the Tokyo metropolitan expressways is an essential part to keep the roads in good condition at all time. Inspection program at present is more systematic and effective than it in early stage.

Inspection is roughly grouped into two kinds. One is inspection by checking design data (data inspection) and the other is in-site inspection. It passed over 20 years since the beginning of construction of the expressways so that the applied standards for design, construction and materials were often revised. There are some structures which are in no conformity with the present standards, and they are certainly to be deteriorated under changing condition. The Corporation has enourmos amounts of drawings and sheets of calculations on design procedure of elevated bridges which are kept on micro-film or fiche, and now are being stored in the computer. Data inspection is to check these data and to pick up the structures under critical condition both analytically and experimentally. Such structures are to be investigated through in-site inspection.

In-site inspection is grouped into three; patrol, periodic and special inspection. Patrol inspection is the most widely used method. It is made by trained inspectors from cars running on the expressways or on the surface streets below the expressways through visual investigation. This inspection is very rough one, but the Corporation perseveres in efforts to detect any defects and to maintain traffic lanes in a serviceable condition.

Periodic inspection is to examine the structural details carefully and closely with eyes, photos and some instruments from on scaffolding or mobile platforms. This inspection is usually undertaken by annual plan based on data inspection. And if any defects are found by patrol inspection, the successive surveillance of the structures is added to it.

Special inspection is done whenever critical circumstances such as earthquake, fires or vehicles impacts affect the structures of the expressways.

A procedual flow diagram of these inspections is shown in Fig 4. Severity of defects written in Fig 4 is as follows;

Assessment of patrol inspection is classified into I, II and III.

(I) Defects which give serious trouble to traffic or affect people below the elevated bridges
(II) Defects which give some trouble to traffic or affect environmental impacts on the residents along the elevated bridges
(III) Defects which give a little trouble to traffic

Assessment of periodic inspection is classified into A, B, C, D and Q.

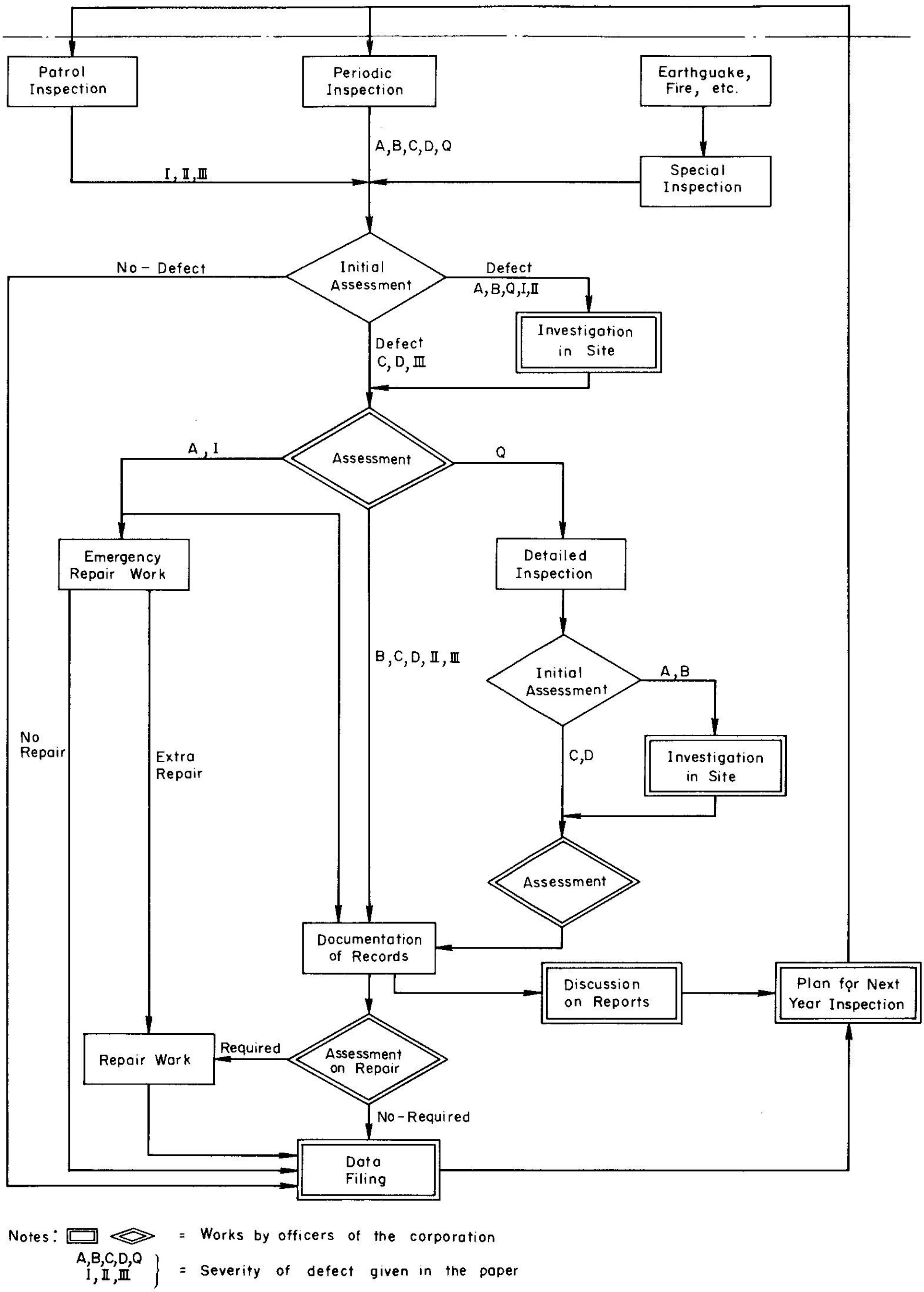


Fig 4 Procedural flow diagram of inspection

Kinds of inspection \ Structures		Concrete structures			Steel structures			Wearing surface	Joints	Handrail	Floor slabs	Bearings	Paint	Emer-gency exits	Aseismic devices	Others	Intervals of inspection
		Girder	Pier	Tunnel	Girder	Pier	Bolt									Drainage,noise barrier,etc.	
Patrol inspection	Frome the traffic lane (Daytime)	Visual inspection from the patrol car running on the expressways (mainly serviceability for traffic)															Once a day
	〃 (Night)	〃 (lighting poles , guide signs, etc.)															Once a week
	From the ground (Daytime)	Visual inspection from the patrol car running on the surface streets (the under surface side of the bridges)															Once a week
Periodic inspection	Visual inspection from the ground (mainly on-foot)	○	○	○	○	○	○		△	△	○	△	○	△	△	△	Once a year
	Photo or visual inspection from the ground	○	△		△	△	△			△		○	△				Every five ~ seven years
											○						Every six years
	Photo or visual inspection from the traffic lane									○							Every five years
								○	△								Once or twice a year
	Inspection from scaffolding or mobile platforms				○	○	○		△	△	○	○	△*		○	△	—
		△	○		△	○	△		△		△	○					(Near pier) Every ten years for steel Every five years for concrete
	Inspection by instrument								○								Twice a year
							○										Every ten years
								○	△								—
	Successive surveillance of crack,etc.	○	○	○							○						Twice a year
Special inspection		Case by case															When earthquake, fire, etc. adversely affect the structures

Note : ○ = Full inspection

△ = Partial inspection

* = Inside of box girder

Fig 5 Combination of inspection

(A) Serious defects needing emergency repair
(B) Defects needing repair in near future or attention in repair
(C) Slight or incipient defects needing to record in the document
(D) Slight defects needing not to record in the document
(Q) Defects needing successive surveillance through further inspection - when the cause of them is ambiguous.

In special inspection, the same assessment rate as aboved is used depending on the circumstances because the cause of defects is clear.

Periodic inspection is so well combined that the structures are effectively inspected through various points as shown in Fig 5. The route and the structure to be inspected are determined by the results of data inspections or in-site inspections in the past, with general intervals as shown in Fig 5. Since there are major similarities in types and caracteristics of elevated structures of the expressways, the condition of such structures can be grasped without full inspection for every structures. When some defect is discovered in a structure, the cause of it is detected. If the causes of the defects are common to structures and the same defects often happen, all similar structures are to be inspected immediately or in near future in degree of defect.

The portion of the structures to be inspected, the item to be observed and the instruments to be used are generally preserved due to the types of the structures. Assessment way and rate are so arranged numerically that there is no difference among various inspectors.

3. HISTORICAL VIEW OF ASEISMIC DESIGN PROVISIONS ON HIGHWAY BRIDGES

3.1 Provisions before 1980

When the Tokyo Metropolitan Expressway Public Corporation was established, aseismic provisions on highway bridges in Japan was included in the "Specifications for the Design of Steel Highway Bridges (1956)" issued by the Japan Road Association (JRA). In these provisions, the horizontal design seismic coefficient was taken from 0.10 to 0.35 depending on areas and ground conditions. The vertical design seismic coefficient was also specified as 0.10. But the bridges were generally designed using 0.20 as horizontal coefficient and 0.10 as vertical coefficient respectively as same as in the past.

There were no original provisions when the Corporation started his construction work. But each designer of the Corporation had adopted 0.30 as horizontal coefficient (K_h) and 0.10 as vertical coefficient (K_v) considering that the expressways were only constructed in the Tokyo metropolitan area and on the relatively soft ground, and they would be the most important routes to maintain the capital functions. The expressways designed in this stage were the route Nos 1 and 4.

In 1963, the Corporation had togethered the design criteria which left to the discretion of designers, and established the "Design Standards for the Structures". They contained a chapter for aseismic design, and K_h and K_v were specified to be 0.20 to 0.30 and 0.10 respectively. However, the bridge structures were conventionally designed by 0.30 in K_h. Moreover, another idea was introduced in these standards; i.e. fundamental natural period of structural system was compared with predominant period of the subsurface ground which was computed from a period frequency curve based on the measurement results of micro tremor of the subsurface ground, and, if both had no fear of resonance, the lower design seismic coefficients would be adopted. This idea was applied to some bridges with long fundamental natural period of structural system. It was another remarkable point of these standards that a divice to prevent an excessive displacement on a movable support should be provided in steel girders. The elevated bridges on the route Nos 2, 3 and 5 in the west part of Tokyo were designed by these standards.

As the expressways were constructed widely in Tokyo, the data concerning the ground conditions in the various part of Tokyo were brought together. In 1967, the Corporation issued new "Aseismic Design Standards" in which the design seismic coefficients were given depending on ground conditions and structural types as below.

Table 1 Design seismic coefficients

		Type of ground*			
Seismic coefficients		I	II	III	IV
Horizontal coef.	For structures above the ground surface	0.20	0.24	0.27	0.30
	For structures below the ground surface	0.15	0.18	0.20	0.23
Vertical coefficient		0.10			

* The numbers indicating the types of grounds correspond to the numbers given in Table 2.

Table 2 Classification of grounds

	Ground conditions of alluvium and the Kanto loam layer			
Thickness of alluvium and Kanto loam layer	Sand & gravel	Sand, clay & Kanto loam layer with $N \geq 5$	Soft ground	
			$2 \leq N < 5$	$N^{**} < 2$
0 - 3 m	I	(Foundations should be constructed after completely removing this thin layers)		
3 - 10 m	III(II)*	III(II)	IV(III)	IV(III)
10 - 25 m	III(II)	IV(III)	IV(III)	IV(IV)
Greater than 25 m	IV(III)	IV(III)	IV(IV)	IV(IV)

* The number in parentheses maybe used as the type of ground if rigid foundations are used.

** An N-value is defined as the number of blows necessary to produce a penetration of 30 cm when a hammer weighing 63.5 kg is dropped onto the standard sampler from a height of 75 cm.

On the other hand, it was stipulated that dynamic earthquake response analyses should be adopted for the bridges which were constructed on the extremely soft soil layer, or for which detailed investigations were required. In those days, the route Nos 6 and 7 in the east area of Tokyo with softer soil layers and the Haneda-Yokohama route were designed.

With viewed from damages to the bridges by the Niigata Earthquake of 1964, the Ministry of Construction made haste for issuing new aseismic code. Referring to the standards of the Corporation, the JRA enacted the comprehensive code against earthquake, i.e. the "Specifications for the Earthquake Resistant Design of Highway Bridges" in 1971. The conventional idea against earthquake was basically revised in these specifications. These specifications provided two methods in determining design seismic coefficients. One was the conventional seismic coefficient method. The horizontal design seismic coefficient K_h was specified as below;

$$K_h = v_1 \cdot v_2 \cdot v_3 \cdot K_o \text{ ----------- } (1)$$

where K_h : Horizontal design seismic coefficient
K_o : Standard horizontal design coefficient (0.20)
v_1 : Seismic zone factor depending on the area divided Japan into three parts due to earthquake-prone degree (0.70 to 1.00)
v_2 : Ground condition factor classified in four groups (0.90 to 1.2)
v_3 : Important factor, 1.00 for trunk roads and 0.80 for general roads, but maybe increased up to 1.25 for a special case.

The other was modified seismic coefficient method which was applied to the bridges with highraise piers more than 25 m. In this case, the horizontal design seismic coefficient K_{hm} was specified as below;

$$K_{hm} = b \cdot K_h \text{ ---------------- } (2)$$

where K_{hm} : Modified horizontal design seismic coefficient
K_h : Horizontal design seismic coefficient specified in equation (1)
b : Magnification factor depending on the fundamental natural period of the bridge system and also the ground condition classified in four groups (0.50 to 1.25) (refer to Fig 6)

The vertical design seismic coefficient K_v was usually taken as zero except for the design of bearings or the examination of stability against overturnings.

Since there were the bridges damaged in the Niigata Earthquake by liquefaction of sandy soil layers below the real ground surface, new provision for liquefaction was added to the aboves. In the layers which had or might have a potential for liquefaction during earthquake, it was stipulated that those layers should be ignored in design. The estimation method on whether or not the layer would liquefy was shown in the appendix of the specifications. Provisions for aseismic devices to prevent girders from falling down (fall-proof devices) were stipulated in these specifications at first.

The Corporation had applied these specifications to the structures of the expressways for a while. The Tokyo metropolitan area is one of the most earthquake-prone area in Japan, and then seismic zone factor was 1.00 and important factor was 1.25. But the Corporation intended to revise these specifications because these were complicated in getting design seismic coefficient. When rather high piers on the route No 9 were designed, K_h became 0.38 because the route No 9 would be built on the sofest ground in Tokyo, and moreover the ground of it had a high potential for liquefaction. Such high coefficients spent expensive expenditure.

The Corporation therefore issued the "Practical Use" of the above specifications in 1973. The horizontal design seismic coefficients for the bridges with highraise pier more than 25 m and between 15 m and 25 m were fixed numerically in the "Practical Use" without applying modified Seismic coefficient method. Because there were many bridges with highraise pier between 15 m and 25 m on the expressways, and they were often critical against earthquake under applying just above specifications.

Table 3 Design seismic coefficients for superstructures and piers

	Ground conditions				Remarks
The height of pier	I	II	III	IV	
h ≦ 15 m	0.20	0.22	0.24	0.26	v_3 = 1.1, b = 1.00
15 m < h ≦ 25 m	0.22	0.24	0.26	0.29	v_3 = 1.1, b = 1.10
25 m < h	0.25	0.28	0.31	0.33	v_3 = 1.1, b = 1.25

Note: The value of v_3 may be increased up to 1.25 for special structures, i.e. 1.14 times the value of Table 3.

Table 4 Design seismic coefficients for footings

Level of footings		Ground conditions I	II	III	IV	Remarks
I	Below the design ground surface	0				
II	In the layer which may liquefy	0.10	0.11	0.12	0.13	
III	In the layer which have a high potential for liquefaction	0.20	0.22	0.24	0.26	v_3 = 1.1, b = 1.0

3.2 Current provisions

In 1980, the JRA issued new specifications, i.e. the "Specifications for Highway bridges, Part V, Earthquake resistant Design". These specifications are basically the same as of 1971 except minor changes as follows;

a. To define clearly the soil layers which are judged to be vulnerable for liquefaction using liquefaction resistance factor F_L

where $F_L = R / L$ ------------- (3)

R : Resistance of soil elements to dynamic loads
L : Dynamic loads to soil elements induced by earthquake motion
If F_L is smaller than 1.0, the layer shall liquefy.

b. To apply modified seismic coefficient method to the bridges with high-raise piers more than 15 m

c. In the above case, to use the value of "b" shown in Fig 6 to avoid a sudden change of "b"-value as a period of 0.5 seconds

d. To start checkin ductilities of reinforced concrete pier

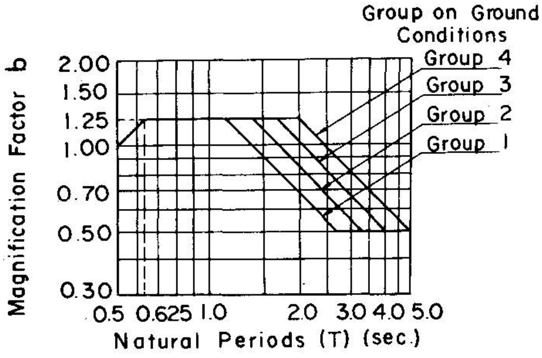


Fig 6 Magnification factor for modified seismic coefficient method

The Corporation basically applies these specifications to the structures of the expressways, and then issues the "Practical Use" again. New "Practical Use" adopts modified seismic coefficient method for the bridges with highraise piers more than 15 m, and shows how to determine the design ground surface by

F_L and pier height.

In the case of liquefaction resistance factor $F_L > 1.0$, the design ground surface is generally laid beneath the bottom surface of the footing, and it may be laid above the top surface of the footing if the real ground surface can be taken as the design ground surface for earthquake-resistance, considering the conditions of grounds at present and in future included back filling after excavation. In the case of liquefaction resistance factor $F_L \leqq 1.0$, the design ground surface is taken as shown in Fig 7. For the soil layers with $F_L \leqq 1.0$ and within 10 m of depth from the real ground surface, bearing capacities and other soil constants shall be either ignored or reduced as shown in Fig 7, by multiplying the original values by reduction factors D_E.

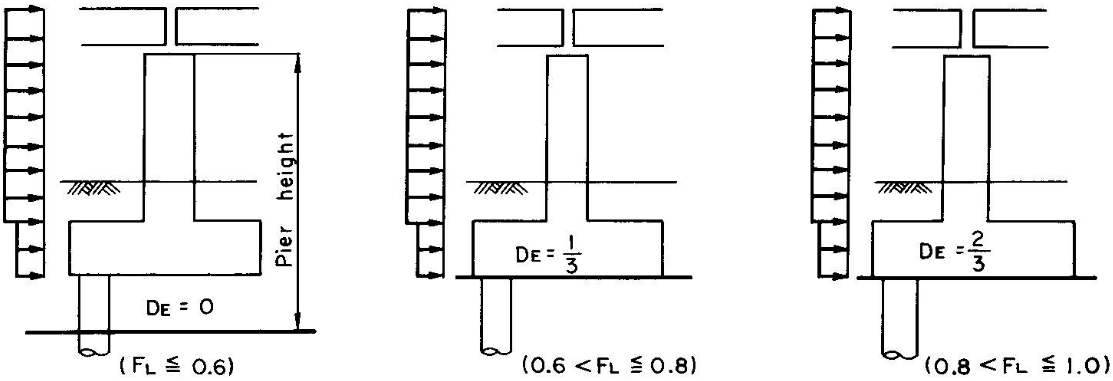


Fig 7 Relationship between F_L and D_E

Table 5 Design seismic coefficients

	Ground conditions				Remarks
Horizontal coefficients	I	II	III	IV	
For superstructures and pier bents	0.20	0.22	0.24	0.26	v_3 = 1.1, b = 1.0 h $\leqq$ 15 m
For footings, abutments, etc.	0.18	0.20	0.22	0.24	v_3 = 1.0

4. EMERGENCY PREPAREDNESS FOR THE EXPRESSWAYS BEFORE AND AFTER EARTHQUAKE

4.1 After an earthquake warning issues

The council comprising six seismological experts, specially assigned by the Japanese government, is set up in Japan. When data sents to the Meteorological Agency in Tokyo recorded abnormal observations in the earth crust, the experts hasilly assemble at the agency and analyze the data. If their conclusion is that a major earthquake is imminent in some area, especially in the Tokai area (the west direction close to Tokyo) where is the most likely to strike, the prime minister issues a warning against such an earthquake. The warning includes anticipating epicenter, magnitude or intensity and time.

If a big earthquake strikes the Tokai area, the Tokyo metropolitan area is anticipated to have a big damage. Therefore, the central government as well as the local governments concerned immediately takes measures necessary to secure the maximum safety of their residents. The Metropolitan

Expressway Public Corporation is also designated by the prime minister as a designated public organ as provided in the "Law on Prevention for Disaster". When a warning is issued, the Corporation operates a predetermined emergency system in various fields to take emergency measures.

From a technical point of view, an emergency preparedness is provided. It is a kind of special inspection. The following matters are predetermined on the way of special inspection after a warning against earthquake is issued; i.e. subjects to be inspected, types of instruments and cars to be used, numbber of a group to cope with, courses to follow, speed to run, etc. Main subjects to be inspected are as follows;

* Operation test of a wireless communication system
* Operation test of an emergency electrical power supply system
* Operation test of emergency telephones, television cameras for monitoring, variable message boards, warning equipments, fire fighting equipments, etc.
* Check of inspection instruments and materials
* Inspection of scaffolding platforms for ordinary repair works, or removing of them if necessary
* Check or supply of dead batteries, lack of paper and instruments themselves for strong-motion seismograph installed on various points of the expressways
* Enough supply of fuel for patrol cars and vehicles for inspection
* Emergency measures for the structures having serious defects against strong earthquake.

The anti-quake drill for such an earthquake with strong magnitude is held on September 1 of every year, as memory of the Kanto Earthquake Day.

4.2 Special inspection immediately after earthquake hits

The way of special inspection is provided in detail, when an earthquake hits the Tokyo metropolitan area unfortunately. The special inspection differs in degrees on intensity of earthquake on the Japanese scale of seven.

No work is done below intensity of two. If intensity of earthquake reaches three (8 to 25 gals), rough inspection is done. Such a degree of earthquake often hits the Tokyo metropolitan area, but there is no damage to the structures of the expressways. However, scaffolding platforms for ordinary repair work are inspected visually from on patrol cars or on-foot. The inspectors follow the predetermined course within an hour.

The earthquake with intensity of four (25 to 80 gals) usually hits Tokyo once or twice a year. In this case, the expressways are inspected visually from patrol cars running on the expressways taking the predetermined courses for about an hour. On the other hand, the under surface of the elevated bridges is checked from patrol cars running on the surface business streets for about three hours. This inspection is done in the same way for intensity of five (weak: 80 to 150 gals, strong: more than 150 gals).

Moreover the structures to be checked through visual inspection on-foot are designated at an earthquake with intensity more than four. These structures include the bridges on each route which are necessary to be paid an attention at earthquake by the inspection mentioned in Chapter 2 or which may have the insufficient strength against earthquake pointed out by the data inspection mentioned in Chapter 5. For example, there are nine bridges on the route No 1, such as the bridges installed an oil damper on each support, rehabilitated cracks of piers and strengthened dapped end of girders in the past. It takes an hour and half at intensity of four, two hours at intensity of five (weak) and three hours at intensity of five (strong) to inspect.

Twenty one strong-motion seismographs were installed in the bridges with higher raise of pier and complicated system, beneath the ground with soft soil layer along the route, etc, and nine of them are out of order. These records have been periodically collected in usual time and gave a great contribution to the earthquake-resistance design of structures up to the present. When an earthquake more than intensity of four strikes the structures, these records are collected at once and analyzed. If any extraordinary motion and accelaration are obtained, a further special inspection is to be undertaken.

When a big earthquake hits Tokyo and it brings the worst situation which paralyzes functions of surface roads, the expressways are to be closed immediately for ordinary vehicles and to be used as exclusive roads for the emergency services such as rescuing, policing and fire fighting activities. To secure these proper use of the expressways, the Corporation always endeavors to let the public know the following matters;

* Drivers should act calmly even against a major tremor, and decelerate their vehicles to stop, taking care of the other cars in front and at rear, in order to avoid accidents.
* To insure the preferential passage of emergency cars, drivers should stop on the left side of each road, with the right lane opened as widely as possible.
* Drivers should escape from the nearest ramps or emergency exits leaving key in the ignition.

5. UPGRADING WORKS OF THE BRIDGES AGAINST EARTHQUAKE

5.1 Data inspection against earthquake

As mentioned before, the bridge structures of the expressways have been designed to be safe at the time of earthquake such a magnitude as the Kanto Earthquake. However, the aseismic code has been often revised as mentioned in Chapter 3. It is necessary to know in what condition the structures are under the newest aseismic code and to repair or to rehabilitate the structures which may have insufficient strength against earthquake. The following procedure is taken in data inspection against earthquake for provisions of 1980.

At first, applied design seismic coefficients are investigated. It is possible to pick up them because the year of design of each route is recorded and design procedures of the bridges are kept. But their amounts are enormous, and it is impossible to check each bridge. Then a map concerning applied design seismic coefficients for each route is drawn up by adequate sampling.

While a map of ground and soil conditions is made up based on geological data used in design and boring data obtained at construction. Using this map, new design seismic coefficients are computed. Liquefaction resistance factor is also calculated, and assessment for liquefaction is done. Due to the value of F_L, the level of the design ground surface is determined. Moreover the height of pier is checked concerning whether modified seismic coefficient method shall be applied or not.

If there is some risk in difference between applied value and computed value in seismic coefficients, in the level of the design ground surface, etc, the bridge is redesigned by both working stress design and ultimate strength design methods and is examined its safety.

Since the bridges on newly constructed routes except the numbered routes (the route Nos 1 to 8) are designed by relatively new provisions, there is no problem. In comparison with only horizontal design seismic coefficients, the bridges on the numbered routes were safe against earthquake because they had been applied K_h = 0.30 or partially K_h = 0.27, because new provisions specify that K_h is 0.22 to 0.26. When the bridges with highraise piers more than 15 m were examined, a couple of bridges on the route Nos 5, 6 and 7 was assessed to be slightly unsafe. But it was proved from the result of redesign that they had enough strength against earthquake.

Provision for liquefaction of sandy soil layer is so relatively new that critical problem is detected. There is no risk against liquefaction concerning the route Nos 2, 3, 4 and 5 in uptown and in the west area of Tokyo. But the bridges on the route Nos 6 and 7 in the east area of Tokyo and the route No 1 along the coastline of the Tokyo bay have a potential for liquefaction during earthquake. Moreover it is necessary for them to let the design ground surface down and the design horizontal forces increase on large scale. Some of them are already upgraded if possible, and the others are under successive surveillance, or are designated as the bridges to be paid an attention at earthquake. Moreover they are being surveyed by dynamic earthquake responce analyses inputting quasi-seismic waves. However the number of them is a little.

5.2 Upgrading work concerning aseismic devices

In a series of bridges such as the Tokyo metropolitan expressways, if a part of them falls down during earthquake, it is impossible to serve a function as roads. The Corporation give priority at present to installation of aseismic devices to prevent girders from falling down (fall-proof devices).

These devices had been installed from so early construction stage as mentioned in Chapter 3. But most of them had insufficient strength against earthquake. Year by year, structural details of them were being improved as shown in Fig 8. The basic idea of the present criteria concerning them is as follows;

1) First of all, stoppers should be provided to prevent that upper shoe deviates from lower shoe at movable support.
2) And then it is necessary to satisfy either of the followings.
   a. Both girders between different spans and on the same pier shall be connected to prevent against falling down when either of them deviates from pier top.
   b. Enough length shall be provided, to prevent girders deviating, between the end of support and edge of substructure or between the end of girder and the edge of substructure.
   c. Restriction devices such as projection shall be provided against a large relative movement between girders and substructures.

This upgrading work started from 1971 following new criteria. Compared with constructing the bridges newly, the upgrading work on the existing expressways is done in worse condition; i.e. narrow in working space, no good in workability, undesirable in cutting, holing and welding existing girders, impossible in installing them due to girder arrangement, etc.

Taking an example of steel girder bridges, working procedure is shown in Fig 9. Fig 10 shows various kinds of these devices. The steel bridges on

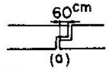
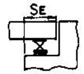
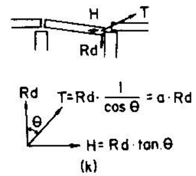
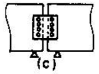
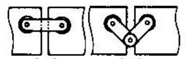
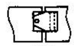
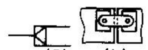
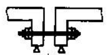
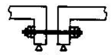
		①	②	③	④	⑤	⑥	Remarks
		April 1963 ∿ April 1965	April 1965 ∿ April 1969	April 1969 ∿ January 1971	January 1971 ∿ September 1973	September 1973∿ April 1980	April 1980 ∿	
Japan Road Association		No provisions	No provisions	No provisions	April, 1972 (1) To increase the width of the pier top $S_o > 20+0.5\ell$, for $\ell \leq 100^m$ $S_o > 30+0.4\ell$, for $\ell > 100^m$ (2) To connect the girders to prevent against the falling down of girders from the pier (3) Overlapped length of the dapped end ≥ 60cm  (a)	The same as left	April, 1980 (1) To provide stoppers to prevent the upper shoe from deviating out of the lower shoe at movable support (2) To satisfy either of ① or ② ① To provide the length of S_E in Fig (b) as follows  (b) $S_E > 70+0.5\ell$, for $\ell \leq 100^m$ $S_E > 80+0.4\ell$, for $\ell > 100^m$ ② To provide an aseismic device to prevent against the falling down of girders 1) To connect the girders and substructure 2) To provide projections set up at the girders or substructure 3) To connect adjacent girders (No provisions in design loads)	$D\ell$: Design load Rd : Dead load reaction fay: Allowable stress (Yield point stress) faa: Allowable stress (Allowable stress for service load) S_E: Length between the end of the girder and the edge of the substructure So: Specified length, in JRA, between the end of the support and the edge of the substructure S: Length between the end of the support and the edge of the substructure ℓ: Span length of the girder d: Horizontal deflection of the pier top caused by seismic force a: Increased coefficient of load (Generally $a = \sqrt{2}$, by considering $\theta = 45°$)  (k)
Metropolitan Expressway Public Corp (MEPC)	Steel girder	To provide a device to prevent an excessive displacement of a movable support $D\ell$: 0.2∿0.3Rd	To provide an aseismic connection device in simply supported girder bridges  (c) $D\ell$: Horizontal force equivalent to the design seismic force	To provide an aseismic device to prevent against the falling down of girders  (d) (e) $D\ell$: 0.6Rd....fay (To apply to continuously supported girder bridge)	(1) Wide pier top $D\ell$: 0.6Rd .... fay (2) Narrow pier top (f)  (f) $D\ell$: 1.0Rd .... faa (3) Narrow pier top (g)(h) (When girders are out of position)  (g) (h) $D\ell$: aRd ... faa (a > 1.0)	(1) To increase the width of the pier top S > So + 2d (2) ① Narrow pier top(f) $D\ell$: 1.0Rd..faa ② Narrow pier top(g)(h) $D\ell$: aRd...faa ③ To provide a restriction device against the movement between the girders and piers  (i) $D\ell$: 0.6Rd..faa		
	Concrete girder	No provisions	1966 For simply supported composite girder bridge only  (j) $D\ell$: 0.3Rd	The same as left	March, 1971 (To add the T-shaped girder bridge)  (j) $D\ell$: 0.6Rd ... fay	The same as left	The same as left for MEPC	

Fig 8 Change of provisions on fall-proof devices

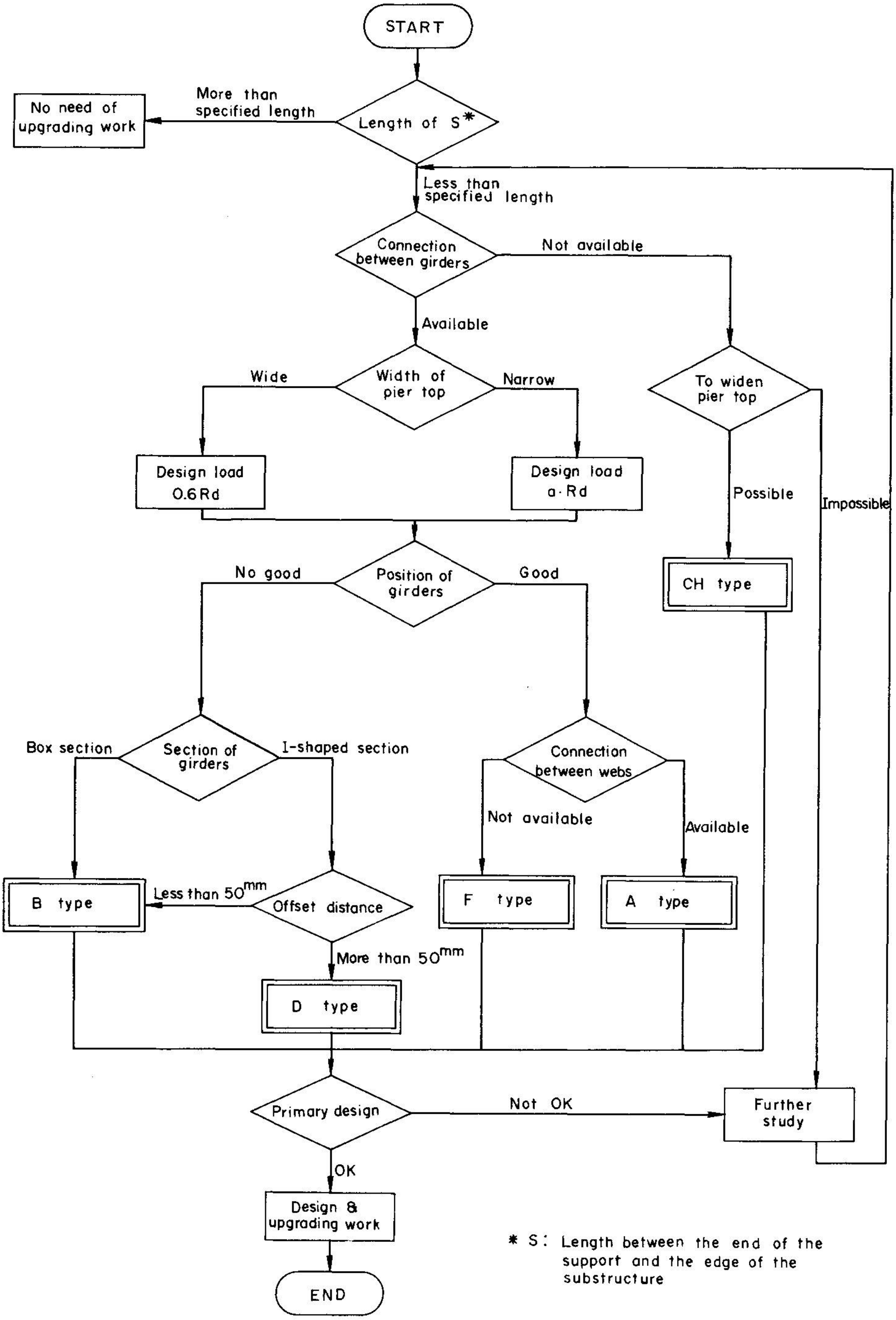


Fig 9 Procedural flow diagram on installation of fall-proof devices

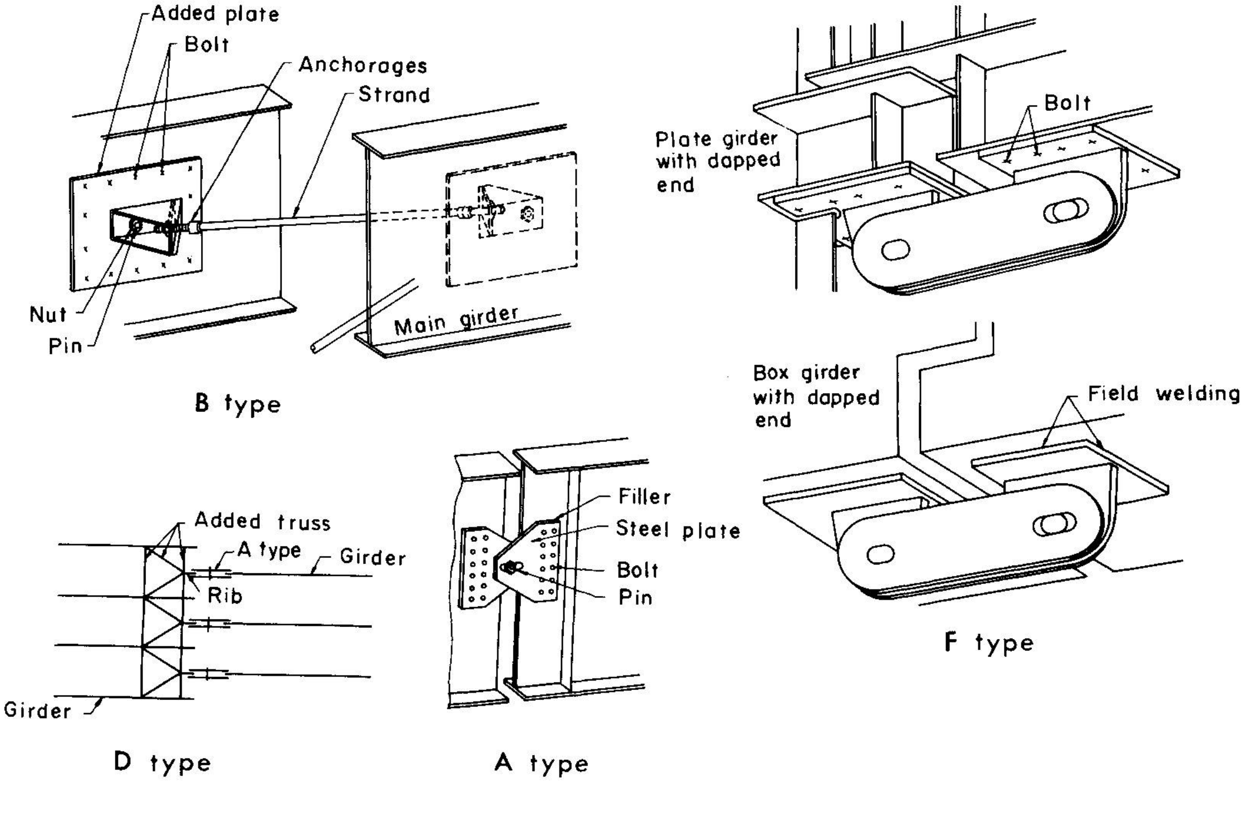


Fig 10 Various types of fall-proof devices for steel girders

1,500 piers were already upgraded, and almost bridges will be upgraded in 1982 except impossible cases.

The installation of connecting devices in concrete bridges is so rather difficult that other retrofits have been devised. For example, they are to widen pier top with concrete placing and prestressing it, and to install restriction devices against the movement of girders as shown in Fig 11. Upgrading work for concrete bridges is done about fifty per cent.

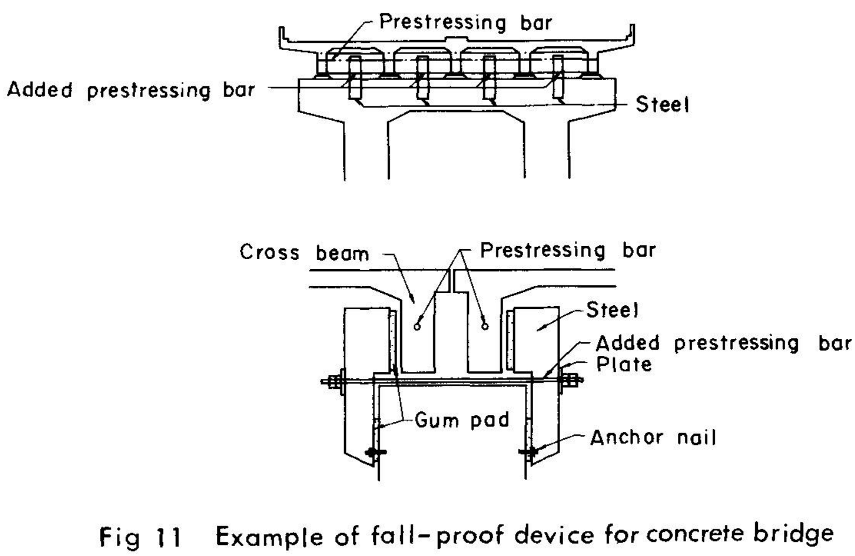


Fig 11 Example of fall-proof device for concrete bridge

5.3 Other upgrading works against earthquake

It was reported that bridge damage due to the Miyagi-ken-oki Earthquake of 1978 concentrated on bearing supports and adjoining portions. Various defects concerning bearings are observed through periodic inspection and as of installation of fall-proof devices. Plate bearing shoes are mostly adopted as support system of the expressways, and their defects are failure of side block of shoes, crack of concrete near bearing supports, cut-off or bent of anchor bolts of bearing stiffening plates, lack of concrete or mortar below shoes due to poor workermanship, etc.

Some of them can be covered through the installation of fall-proof devices against earthquake. Of course, serious defects are rehabilitated, by moving the support to the temporary supports and reinstalling new bearings, casting concrete in the portion near bearings and prestressing it, etc. It is too difficult to repair bearings and adjoining portions without closing the traffic on the existing bridges. It seems that breakage of bearing support during earthquake reduces serious failure of the bridge girder and also of the substructure. Therefore, it is not always advised to rehabilitate bearings too strong. Now the Corporation is studying an effective repair program on bearings as well as fall-proof devices.

Emergency exits, which were constructed at early stage, are simple in structural type and are provided at rough intervals. According to the present criteria, they should be provided at intervals of one kilometer and structural details of them are also specified. The number of exits is being increased now, while the simple ladders are being upgraded to the ladders with cages in the rear, or solid spiral staircases and dog-legged staircases as far as possible. Drivers may escape down from the expressways using them safely at earthquake.

6. CONCLUSION

The inspection and maintenance works of the Tokyo metropolitan expressways are summerized making a point of measures against earthquake. Since the expressways have been designed, constructed and maintained paying progressive considerations against earthquake, they may be in almost safe at earthquake such a magnitude as the Kanto Earthquake.

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