REVISION OF THE HIGHWAY BRIDGE SPECIFICATIONS FOR PERFORMANCE BASED DESIGN

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ABSTRACT

In Japan, the revision of the Highway Bridge Specifications for performance based design is now under study. This report describes the background and objective of the revision as well as the outline of concrete changes. The revision is designed to put into practice (1) more transparent standards to address internationalization, (2) more flexible standards to deal with diversification of, for example, structures, (3) more concrete standards with emphasis on maintenance and durability in addition to safety, and (4) standards promoting introduction of new technologies and methods aimed at cost reduction. The report outlines principal contents of the revision.

KEY WORDS：
Performance Based Design
Required Performance
Specifications For Highway Bridges

1. INTRODUCTION

A wave of revolutionary changes is buffeting public works projects. For example, performance based ordering of structures, and performance based design in which performance is specified as a technical standard. Performance based design is not only useful in comparing regulations and standards but leaves room for greater freedom and ingenuity. Moreover, it will likely streamline establishment of standards. In this context, work is being carried out on development of performance based technical standards.

2. BACKGROUND AND OBJECTIVE OF REVISION

The revision of the Highway Bridge Specifications for performance based design is aimed at fulfilling the following four objectives.

(1) More transparent standards to address internationalization

Technical competitiveness is required of Japanese engineers who will take part in overseas construction work. The current Specifications for Highway Bridges have been worked out of necessity to implement a large number of projects in a short period, building barriers to proposal and introduction of new technologies. What's worse, they have tended to reduce incentives for engineers to develop new technologies.

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With many regulations based on empirical rules, the current specifications have created the impression of not being transparent in the mind of engineers outside Japan, causing the misunderstanding that the specifications are non-tariff barriers. Another factor is a growing movement toward international unification of technical standards in ISO.

(2) More flexible standards to deal with diversification of, for example, structures,
With growing diversification of users' (taxpayers') needs, it is essential to pay attention to costs, structural forms, modeling, landscapes and harmony with a neighboring environment as well as safety. Toward this end, forms of ordering and contracts have been diversified, including VE, DB and PFI. In some cases, however, the current specifications put up barriers to new attempts because they give the impression of limiting engineering methods.

That technical standards limit introduction of new technologies and forms of ordering is not what such standards should be. Therefore, it is desirable to change into more flexible standards.

(3) Emphasis on maintenance and durability
Japan has a vast amount of highway bridge stocks, many of which are rapidly aging. Expenses for their maintenance are growing year by year, and their share in the overall road investment is on the increase. Proper and effective maintenance is necessary, and it is indispensable to adopt structures with high durability at a time of designing.

Although the current specifications contain such expressions as “in the light of durability” and “convenient for maintenance,” most are highly conceptual and lack concreteness, serving as a roadblock to construction of durable bridges. In this respect, it is necessary to establish specific regulations on durability with a view to designing and building durable bridges in future.

(4) Early achievement of results, including cost reduction
Recent efforts for cost reduction have produced new ideas on bridge structures and designing, completely different from conventional concepts. Among problems arising from the new ideas is that new technologies for excellent structures are not used simply because they are not included in the current specifications. Another is that importance is given only to appearance, resulting in less safety and shorter durability. It is required to make some minimum reference to new technologies with good evaluation in the Specifications for Highway Bridges for the purpose of their early introduction.

In summary, it is necessary to clarify what technical standards pursue and facilitate development and introduction of new technologies designed to achieve objectives, and to enhance technological edge at an early date. This complies with the basic idea of performance based design that required performance is clearly specified and that several methods are permitted. This is the reason for the revision of the Highway Bridge Specifications for performance based design.

3. HIGHWAY BRIDGE SPECIFICATIONS AND PERFORMANCE BASED DESIGN.

(1) Performance based design and specifications based design

Table 1 shows a comparison between performance based design and its opposite concept, specifications based design. Actual technical standards usually lie between specifications based design and performance based design, and the proposed revision is designed to move closer to performance based design.

(2) Performance based ordering, designing and regulations

In order to induce ingenuity and use new technologies and new methods, it is necessary not only to give greater freedom to designing but to pay due attention to "ordering" and "regulations."

In the area of ordering, new methods have already been tried with expectations placed on technology proposals. They include a kind of "performance based ordering," such as VE, DB and PFI. In order to make these attempts a success, it is essential to revise "regulations" to permit alternatives. This means it is necessary to make efforts for the revision aimed at performance based design.

(3) Conceptual model of performance based design

Figure 1 shows a conceptual model of performance based design and presents minimum words necessary to understand performance based design.

In the figure, it is "required performance" that occupies the upper three stages of the triangle. It is classified into "objective," "functional requirements" and "standards

Table 1 Performance based design and specifications based design

	Specifications Based Design	Performance Based Design
Nature	● To specify concretely materials for use, forms and dimensions	● To describe only performance as objectives of regulations
Merits	● Concrete ● Understandable to anyone ● High designing competence not required ● Easy to examine compliance	● Greater freedom and flexibility for designing ● Clear target performance to be realized ● Easy to accommodate technological progress ● Contribution to international harmony of standards
Demerits	● Rigid ● Unclear target performance to be realized ● Lack of alternatives causing barriers to technological progress ● Likely to become non-tariff barriers	● Advanced technique required to examine compliance ● High designing competence required

required by performance description" in the downward order. The lower the stage, the more concrete the description of requirements. In brief, required performance has a variety of levels. What should be done is to what extent requirements will be determined as given technical standards and which will be left to the discretion of designers.

In parallel to "required performance," there are "verification methods," a theoretical way of determining whether required performance is met or not. Specific possible methods are an analytical model and a test method. It may be a kind of verification method to calculate stress of each part from sectional force and make a judgment in comparison with permissible stress.

It is an ideal to provide verification methods for respective required performance. In actual designing of bridges, however, empirical judgment is often made, and verification methods are not always available for all the required performance. Available as a solution to this problem is "presumed compliance specifications." It is a concept that the past results can verify the performance regarding such elements as dimensions, shapes and materials, which have long proved effective empirically. If conventional methods are described as "presumed to satisfy the requirements, provided the following specifications are met," it will be easy to make coordination with existing bridges and reduce the number of bridges failing to comply with the specifications.

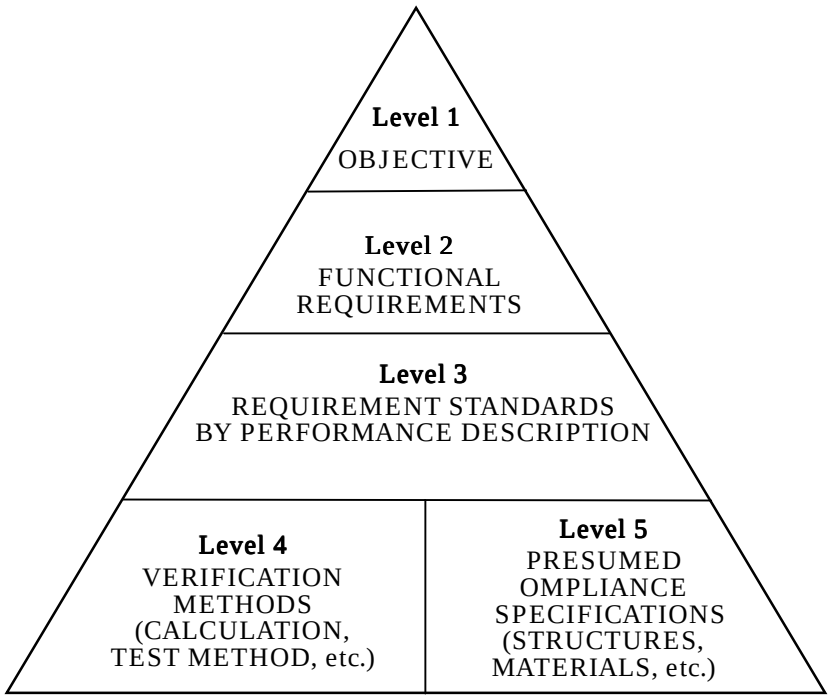

Figure 1 Conceptual Model of Performance Based Design

4. CONCRETE TASKS FOR REVISION AND TIMELINE

(1) First phase with priority given to reform of consciousness

The work on full-fledged performance based design requires various kinds of study, and it will likely take a long time to complete all the tasks. This means the afore-mentioned objective of an early revision cannot be achieved. Therefore, the work on the revision demands speed. At the same time, it is an essential requirement to contain to the minimum a possible chaos where systems and economic structures are intertwined in a complicated manner and to introduce ideas on new regulations smoothly. In this context, it has been decided to carry out the revision in two phases.

In the first phase, the "presumed compliance specifications" will be utilized because it is considered a top priority to revise the Specifications for Highway Bridges toward performance based design in a short period. In other words, requirement provisions will be identified in each article and explanation of the current Specifications for Highway Bridges, described at the beginning and treated as "presumed compliance specifications." It is an ideal to specify numbers for required performance. In reality, however, it is difficult to provide indexes for all the performance. Therefore, required performance will first be described, even in literary expressions, to permit incompleteness.

Required performance in literary expressions can be applied if construction work is an experiment to meet the written requirements or such requirements can be satisfied by other methods. The character of the Specifications for Highway Bridges will show a dramatic turnabout from "work must be carried out as written in the specifications" to "work may be done this way," reducing resistance to introduction of new technologies. As the "presumed compliance specifications," the current regulations will remain as they are, making it possible to avoid confusion in actual designing.

(2) Second phase aimed at completion of system

The second phase is designed for transfer to complete performance based design. This will probably take long, and the revision work will be launched immediately after the completion of the first phase. The following are possible tasks in the second phase.

① Legal status of the Specifications for Highway Bridges

The current Specifications for Highway Bridges are a notification from a Director of the Ministry of Land, Infrastructure and Transport, not a Ministerial ordinance or a government ordinance. While the specifications contain only some regulations for which the government takes responsibility, many provisions are technical standards or standard specifications. Therefore, it is necessary to divide the regulations into technical criteria (required performance) and technical standards or specifications (solutions), all of which the government should take charge of, and to give appropriate legal status to each.

② Review of organization

The specifications consist of provisions in accordance with materials for use and parts of bridges. This applies particularly to Chapters Ⅱ (steel bridges), Ⅲ (concrete bridges) and Ⅳ (substructures). This organization is considered a barrier to liberal concepts covering several areas, such as composite and compound structures, and monolithic structures. It is necessary to divide chapters into regulations on required performance and verification methods for bridges and those on member designing and materials.

③ Establishment of a committee

It is necessary to review of establishment of a committee in case of reorganize a legal status of the Specifications for Highway Bridges and review of organization. Toward performance based design, it is necessary to set up a kind of certificate authority which will study validity of verification methods and presumed compliance specifications and make a judgment

④ Change of forms

The specifications will be changed to conform to the forms of the partial safety coefficient design method, which is becoming an international rule. This will accompany changes in verification methods, in addition to forms. This step will be launched immediately after the completion of the first-phase revision because it takes time to make coordination with existing regulations and it is urgent to change the specifications into forms in compliance with unification of international technical standards.

5. SUMMARY OF MAIN REVISION

ITEMS IN EACH CHAPTER

Main revision items in each chapter will be described briefly. The revision is now under study, and some may be subject to change in future.

5.1 PART Ⅰ：Common

(1) Designation of design service life, introduction of LCC

In order to provide concrete regulations on durability, it is essential to establish service life as a target in designing.

It is desirable to set as long a period as possible for service life in view of the current stocks of highway bridges in Japan and their aging. However, care should be taken not to set too long a period, which will likely lead to excess safety in designing fatigue limit state scheduled to be introduced in the proposed revision, and durability against neutralization of concrete and damage from salt to concrete. It is a fundamental principle to set design service life based on various conditions, and a candidate period is 100 years in the light of examples in Europe and the United States. The designation of design service life can help work out maintenance plans with emphasis on durability and, as a consequence, reduce costs necessary for maintenance.

Another concept aimed at a future reduction in maintenance costs is minimization of life cycle cost (hereinafter referred to as LCC). Types of costs to be considered for LCC or ways of minimization have not yet been established, and it is difficult to make an accurate calculation of long-term costs. From the accumulated experience, the Public

Works Research Institute will make data available for rough calculation of LCC regarding parts requiring renewal of members in maintenance, such as floor system, bearing, expansion unit, and painting of steel bridges.

(2) Full records of maintenance

The specifications will stipulate that designers shall specify maintenance plans they work out at a time of designing in design documents and others, and show concrete examples in order to help carry out and take over maintenance. This means designers consider maintenance methods and can contribute to construction of structures with longer durability. Moreover, data necessary for maintenance can be stored in an effective way. This provision is also expected to promote technology development aimed at durability.

Also under study is the provision to make it mandatory to record large-scale maintenance, including improvement of load resisting force and replacement of floor system, in such books as a bridge register.

(3) Load

Although the fundamental organization is not subject to change, forms will be changed in view of the second-phase revision. The combination of loads will be changed at a time of transfer to the partial safety coefficient design method.

Specifically, a live load is given as a given condition. Regarding other loads, the specifications stipulate that designers can set load strength by improving accuracy of calculation in case it is clearly unreasonable to use existing regulations in the light of structures and conditions of a bridge construction site, and adequate data are available. As regards earthquakes, it is realistically difficult to set seismic force based on various conditions, and conventional values will be used. However, the specifications will specify items that should be considered in the perspective of future research.

It was studied to handle the effects of such durability damaging factors as salt attack, corrosion and fatigue as “actions” to bridges in the same way as loads. In view of slight familiarity of such handling, specific measures will be stipulated in each chapter.

As for such loads as wind and earthquakes, conventional values will be used, even if design service life is specified in the latest revision.

(4) Allowable unit stress, combination

One of the problems in the revision for performance based design is how safety of structures is regulated in designing. The current Specifications for Highway Bridges in principle stipulate safety by extra coefficients corresponding to allowable unit stress and combination of loads on the basis of the allowable unit stress design method.

In future, it may be necessary to transfer to the partial safety coefficient method. In the latest revision, however, it has been decided to follow the allowable unit stress design method. Therefore, ① the existing regulations shall be preserved for

combination of loads and extra coefficients; and ② with respect to allowable values for each material, conventionally-regulated JIS materials shall be regarded as “presumed compliance specifications,” and similar safety shall be guaranteed for new materials.

5.2 PARTⅡ：Steel Bridges

(1) Introduction of fatigue design

So far, the effects of fatigue have been discounted in designing highway bridges with the exception of steel floor systems. For the following reasons, it has been decided to introduce fatigue design.

① In order to improve durability, it is important to design highway bridges with consideration for fatigue. The concept of a target period in designing has been introduced, creating a climate for the introduction of fatigue design.

② The knowledge on regulation of fatigue design has been accumulated. It is possible to improve fatigue durability by avoiding slight carelessness at a time of designing and implementation. Depending on structures, it is possible to show design methods.

The specifications will only stipulate a basic concept on fatigue design. Concrete design methods will be described in guidelines available separately, together with reference materials, including structural details and trial design examples.

In studying the fatigue design method, attention was given to avoidance of excessive safety, a fundamental concept applicable to various structures, and fewer burdens on actual designing for easy acceptance. A summary of fatigue design follows.

① It should be considered in designing to choose joints and detail structures with higher durability against fatigue instead of joints with small unit strength against fatigue.

② Of main structures like main girders, methods for stress calculation are presented for some, if possible, so that a check can be conducted on durability against fatigue by accumulated fatigue damage during a period subject to designing. T loads will be used in consideration of actual designing work.

③ Some structures are difficult to check with stress, and others are not available for the design method through calculation. For these structures, considerations in designing and implementation, such as structural details and quality control are shown, and the fatigue design means to satisfy such considerations.

Regarding the method through stress calculation, it is necessary to expand the extent of applicability and continue to study how to improve calculation accuracy.

(2) Floor system

Toward performance based design, provisions will be made on basic performance required of floor systems and other considerations. It will also be stipulated that floor systems other than RC floor system, steel floor system and PC floor system can be adopted if they satisfy the required performance.

For new types of floor systems, it is considered difficult to verify durability

against fatigue, which is required performance. The specifications will specify a verification method reflecting the results of the recent research into durability against fatigue of concrete floor systems through a ring load running test device.

5.3 PARTⅢ：Concrete Bridges

(1) Improvement of concrete durability

In recent years, deterioration of concrete caused by the effects of salt attack has been pronounced, and falling off of concrete blocks has made headlines. Most cases of deterioration are considered to have resulted from lack of covering, compounded by neutralization and salt attack.

The Specifications for Highway Bridges stipulate only the minimum covering of reinforcing bars. The "guidelines for measures against salt attack on highway bridges (draft) and explanation" classify measures in accordance with regions requiring measures against salt attack, and stipulate an increase in the minimum covering. This provision will be incorporated in the current specifications. Moreover, the specifications will raise the number of regions requiring measures against salt attack based on the results of surveys on damage from salt attack, and provide for additional measures to prevent corrosion of steel, together with the guarantee of enough covering depth.

Durability of concrete is greatly influenced by management at a time of implementation. With a view to implementation management, various methods have been developed for examination of concrete. For example, study is underway on a method to measure covering depth of completed structures and the water-cement of fresh concrete. It is necessary to make a distinction between structures inspected with these advanced technologies and those examined with conventional methods or those not checked, and to stipulate differences in durability in accordance with frequency of maintenance. For PC bridges in particular, durability is greatly influenced by availability of checks on PC steel.

5.4 PART Ⅳ：Substructures

(1) Clear description of required performance for substructures

In order to make possible the adoption of new technologies and engineering methods required performance for substructures, which has not been specified, will be expressed clearly in connection with functions of bridges. This has also resulted from consideration for a transfer to the partial safety coefficient design method in future.

① Substructures must maintain soundness in order to ensure functions of bridges.
② Damage to substructures must be limited to such a degree as not to prevent recovery of functions, though bridge functions are constrained.
③ Damage to substructures does not lead to destruction of bridges, though bridge functions cannot be ensured.

These three stages are considered required performance of substructures.

The current design method will be described

as one of methods to state clearly and verify the limit state designed to confirm that required performance is ensured when loads estimated in designing work on bridges. In the chapter on designing of each foundation, an organization has been reviewed to clarify relationship between required performance and the design method, and the hierarchy regarding respective articles.

(2) Introduction of new technologies and engineering methods

The chapter on substructures will stipulate required performance of substructures and the limit state for confirmation so that a new type of foundation as well as new technologies and engineering methods can be introduced. Other required performance will be mentioned, as needed, to promote the adoption of new technologies and engineering methods.

Also regulated will be design methods for new technologies and engineering methods, which has proved reliable and effective in reducing costs, and produced favorable results (improvement of "presumed specifications"). The review of requirements for regulation and its process will contribute to promotion of new technologies and engineering methods and to improvement of presumed specifications.

5.5 PART Ⅴ：Seismic Design

(1) Seismic Performance of Bridges

Table 2 shows seismic force to be considered in seismic design and seismic performance targets of bridges. "Seismic performance level 1" is defined as "not to damage soundness," "seismic performance level 2" as "to limit damage in order to recover functions as bridges more quickly" and "seismic performance level 3" as "to prevent fatal damage."

The "seismic performance level 1" is simply defined "not to damage soundness." In performance based design, however, it is important to describe correctly what it means "not to damage soundness." In other words, it is necessary to express clearly that seismic performance has three states—post-earthquake safety, post-earthquake service and post-service restoration—and that post-earthquake restoration has two states—long-term restoration and short-term restoration. Table 3 illustrates required performance for each seismic motion in terms of post-earthquake safety, post-earthquake service and post-service restoration. The seismic performance level 1 stipulates as required performance that safety shall be ensured against destruction of bridges; that pre-earthquake functions as bridges shall be ensured immediately after an earthquake and repair shall not be necessary for post-earthquake restoration of functions; and that long-term repair shall be simple, for example, crack repair for RC members. The seismic performance level 2 provides as required performance that safety shall be ensured against destruction of bridges; that functions as bridges shall be restored quickly immediately after an earthquake and emergency repair shall be enough for immediate post-earthquake restoration of functions; and that long-term repair shall be made easily available. The seismic performance level 3 prescribes as required

performance that only safety shall be ensured against destruction of bridges with no seismic performance in terms of post-earthquake service and post-earthquake restoration. This does not mean, however, that it is necessary to check all the items shown in Table 3. For example, the seismic performance levels 1 and 2, if seismic performance required for post-earthquake service and post-earthquake restoration is satisfied, safety can clearly be ensured against destruction of bridges. In other words, safety is not a dominant requirement in seismic design.

(2) State Limits of Bridges to be Considered in Checks of Seismic Performance

In performance based design, it is important to clarify to what extent behaviors of bridges should be constrained at a time of an earthquake in order to achieve seismic performance shown in Table 2. An entire bridge system and state of each member, which are set for confirmation of seismic performance of bridges, are referred to as state limit.

Table 2 Design Seismic Motion and Required Performance of Bridges

Design Earthquake Motion		Class A Bridges	Class B Bridges
Level 1 (Earthquake motion with a high probability of occurring during a bridge's service life)		Not to damage soundness (Seismic Performance Level 1)	
Level 2 (Large earthquake motion with a low probability of occurring during a bridge's service life)	**Type Ⅰ**	To prevent fatal damage (Seismic Performance Level 3)	To limit damage in order to restore functions as bridges quickly (Seismic Performance Level 2)
	Type Ⅱ		

Table 3 Seismic Performance

Seismic Performance	Safety in seismic design	Service in seismic design	Restoration in seismic design	
			Short-term restoration	Long-term restoration
Seismic Performance Level 1: Not to damage soundness	To ensure safety against destruction of bridges	To ensure pre-earthquake functions as bridges	No need for repair for restoration of functions	Simple repair like crack repair
Seismic Performance Level 2: To limit damage in order to restore functions as bridges quickly	To ensure safety against destruction of bridges	To restore functions as bridges quickly after an earthquake	Emergency repair is enough for restoration of functions	Permanent repair is available easily
Seismic Performance Level 3: To prevent fatal damage	To ensure safety against destruction of bridges	(Restoration of functions may be difficult)	(Emergency repair alone may not be enough for restoration of functions)	(Removal and reconstruction may be necessary)

The current chapter on seismic design does not stipulate state limit of bridges to be considered for confirmation of the seismic performance level 1. It can be described as "state limit where dynamic characteristics and vibration characteristics as a whole bridge system are not greatly influenced by an earthquake. State limit in the seismic performance level 2 will be prescribed as "state limit where plastic deformation happens only to members considered for plasticity, and is fully within the extent of required performance for the members concerned and is not serious enough to make repair difficult." Members subject to plasticity should be selected on the assumption that they can surely absorb energy and be available for repair. It is also necessary to combine, on the basis of structural characteristics of bridges, members which are subject to plasticity and not, and set an appropriate state limit to each member in accordance with such combination.

Bridges have a variety of structural forms, such as girder bridges, rigid-frame bridges, arch bridges, oblique-tension bridges, suspension bridges, and earthquake-immune bridges. Therefore, it is important to study fully which member is subject to plasticity and to which member is plasticity induced on the basis of structural characteristics of bridges and their behaviors at a time of an earthquake.

6. SUMMARY

We have explained the progress so far in the revision of the Highway Bridge Specifications for performance based design. The revision will be carried out in two phases with a view to making full use of advantages of performance based design. The first-phase revision has almost been completed, and the second-phase must be launched with the aim of establishing highway bridge technical standards appropriate for performance based design. It is considered necessary to carry out the revision, while considering overseas trends in technical standards, without hindering the introduction of new concepts.