CHAPTER 2 FUNDAMENTALS OF RETROFIT

2.1 General

In retrofitting, the structure must be designed so it is in keeping with its purpose of use and is both safe and durable, with consideration given to the ease of retrofitting construction and post-retrofitting maintenance, as well as overall economy and environment-friendliness.

[Commentary]

The design requirements in the text must be fulfilled for both new and repaired structures.

As indicated in the text, structures have a variety of performance requirements. Of these performance requirements, retrofitting of structures is performed to improve performance that is directly related to mechanical characteristics. Therefore, methods for quantitative verification of these performance requirements are noted in these (draft) guidelines. **Table C2.1.1** shows the performance requirements that generally relate to mechanical characteristics of structures.

Table C2.1.1 Performance related to the mechanical characteristics of structures

Performance Category	Description
Safety	Performance needed to ensure that the structure does not threaten the lives of users or persons in the surrounding area
Serviceability	Performance such that the structure can be used comfortably and does not cause discomfort exceeding allowable levels to users of the structure and persons in the surrounding area, as well as watertightness and other performance requirements for structures
Restorability	Performance such that the performance can be easily restored if damage is suffered during the service life

The performance that the structure to be retrofitted should possess during its remaining service life after retrofitting is prescribed according to the type of structure, purpose of use, degree of importance and other factors. Also, since "durability" is the structure's resistance to a drop in various performance values, it is related to all performance through time, and so "durability" is not included in **Table C2.1.1**.

In order to evaluate the performance of a structure and verify that it fulfills its performance requirements, it is necessary to express performance in terms of quantifiable physical quantities that represent performance. For example, safety with respect to failure is verified by means of such indices as flexural load-carrying capacity of members, shear capacity, torsional capacity and so on. The indices to be used may depend on the performance evaluation technology being employed. These (draft) guidelines contain calculation methods for indices that can be evaluated using existing technologies. Ideally, technological progress will make it possible to use more advanced methods and enable verification using indices that can express performance values more directly. **Table C2.1.2** shows sample indices when the evaluation methods generally used today are employed to evaluate the safety, serviceability and restorability of structures, as well as when more detailed performance evaluation methods expected to be possible in the future are used.

Table C2.1.2 Sample indices used for performance verification

Performance and Performance Item		Index when general performance evaluation method is used with existing technologies	Index when more precise performance evaluation method is used
Safety	With respect to failure and collapse	Flexural load-carrying capacity, shear capacity, torsional capacity, various types of fatigue capacity, ductility, etc.	Deformation and failure of structure with respect to anticipated load action (evaluation and verification of structure's response to load through numerical simulations)
	With respect to rigid body safety	Resistance moment with respect to toppling	
Service-ability	Driving and walking comfort	Deflection, rigidity, levelness of road surface, level differences, vibration characteristics of structure and foundation, values for speed, acceleration, vibration level and sound level transmitted to drivers and pedestrians, etc.	Perceptions of users and neighbors produced by the response of the structure to anticipated load action and environmental action (conduct evaluation and verification of the interaction between the response of the structure and the perceptions of human beings)
	Resistance to vibration		
	Resistance to noise		
	Appearance	Crack width, crack density, surface soiling, etc.	
	Visual stability	Deflection, crack width, crack density, etc.	
Restorability		Residual displacement, residual crack width, degree of damage to concrete, etc.	Deformation and failure of structure with respect to anticipated load action

2.2 Flow of Retrofitting Process

Retrofitting of structures shall proceed as follows:

(1) Identify the performance requirements for the existing structure to be retrofitted and draft an overall plan from inspection through selection of retrofitting method, design of retrofitting structure and implementation of retrofitting work.

(2) Inspect the existing structure to be retrofitted.

(3) Based on the results of the inspection, evaluate the performance of the structure and verify that it fulfills performance requirements.

(4) If the structure does not fulfill performance requirements, and if continued use of the structure through retrofitting is desired, proceed with design of the retrofitting structure.

(5) Select an appropriate retrofitting method and establish the materials to be used, structural specifications and construction method.

(6) Evaluate the performance of the structure after retrofitting and verify that it will fulfill performance requirements.

(7) If it is determined that the retrofitting structure will be capable of fulfilling performance requirements with the selected retrofitting and construction methods, implement the retrofitting work.

[Commentary]

Figure C2.2.1 shows a flow diagram of the retrofitting process. This flow is based on the "General approach to maintenance" in the (draft) Maintenance Guidelines, with the portions dealing with retrofitting extracted and matters pertaining specifically to retrofitting added.

(2) Inspections of structures to be retrofitted correspond to the "detailed inspections" in the (draft) Maintenance Guidelines. These should be performed in particular to determine whether or not retrofitting

should be performed and gather data needed for retrofitting. Inspections should be performed in accordance with Chapter 5 in these (draft) guidelines and the (draft) Maintenance Guidelines.

(3) The primary criteria for determining whether or not retrofitting should be performed is whether the structure fulfills performance requirements at the time of the retrofitting study. The performance of the existing structure should be verified using methods shown in the Standard Specification (Design) (Seismic Design). However, unlike new structures, with retrofitted structures actual measured values based on the results of inspections can be used for the properties of materials in the structure, section specifications and the like. Accordingly, safety factors used to compensate for uncertainties in the design of new structures can be changed for the retrofitting structure. Also, the effect of such factors as damage to the structure or loss of steel cross-sectional area due to corrosion or the like must be considered when necessary. The method used to determine the design values for the materials in the existing structure is shown in Chapter 3 of these (draft) guidelines.

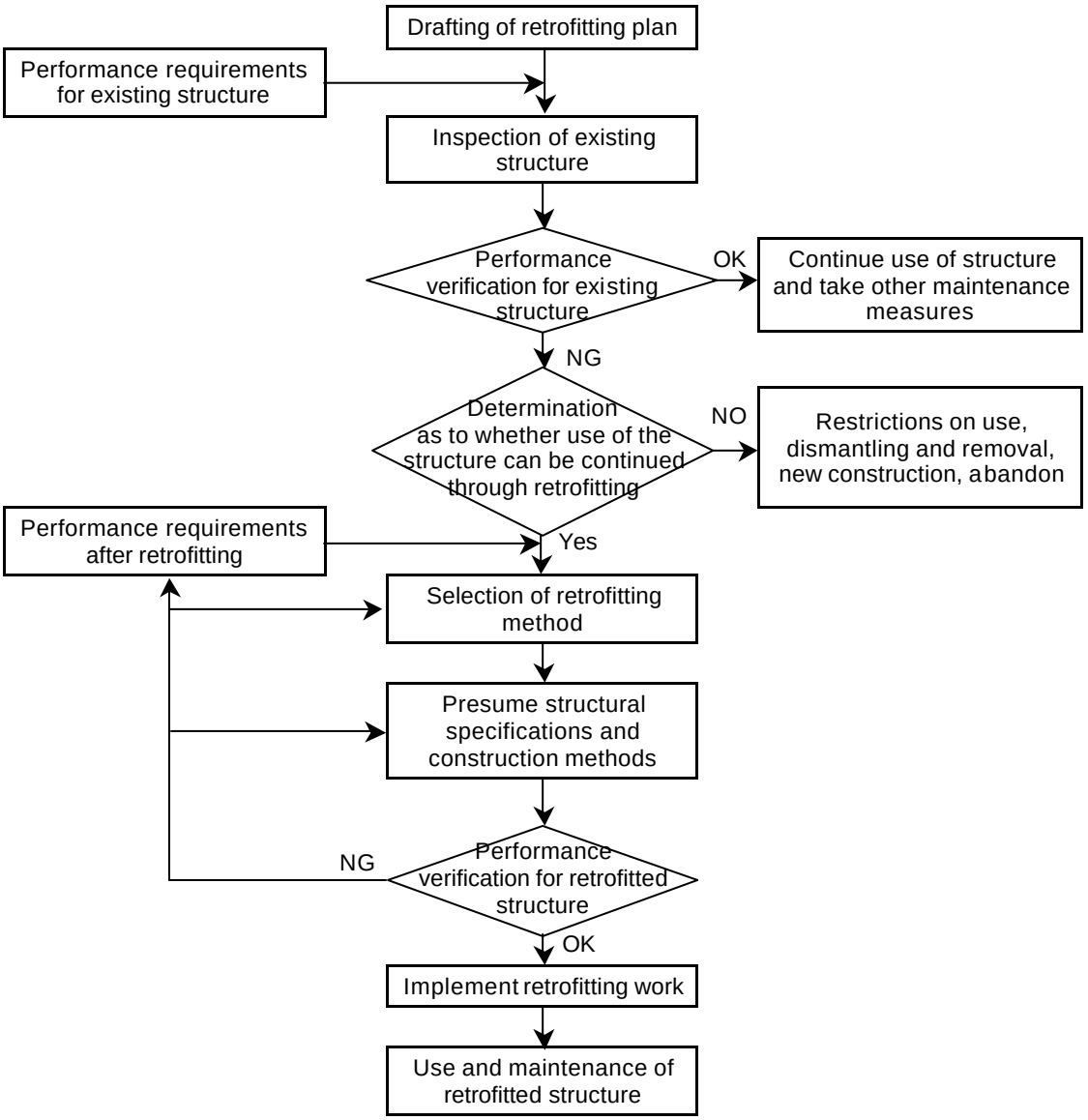


Figure C2.2.1 Flow of retrofitting process

(4) If it is determined through performance evaluation and verification that the existing structure does not fulfill performance requirements, and that use of the structure can be continued through retrofitting, the design process should proceed. In some cases, the performance requirements for the structure after retrofitting will not be the same as those of the existing structure.

Retrofitting of structures includes the following cases:

(i) The performance requirements are the same as those of the structure when it was first built, but because the performance of the structure has declined due to load action and environmental action over time, the structure did not fulfill performance requirements at the time of the inspection; through retrofitting, the performance that would satisfy performance requirements is added.

(ii) The design load has been changed or the structure otherwise requires a higher level of performance than when initially constructed, and therefore it does not fulfill performance requirements; through retrofitting, the performance that would satisfy performance requirements is added.

(iii) At the time of the inspection, the structure fulfilled performance requirements but is predicted to not do so in the future due to a decline in performance due to load action and environmental action over time; performance improvements are conducted to prevent this in advance.

Figure C2.2.2 contains a diagram illustrating these cases. In cases (i) and (iii), a higher level of performance than the structure when first built may be added, or the structure may be restored to the same performance level, or performance at a lower level than the structure when first built, but still satisfying performance requirements, may be added (**Figure C2.2.2** uses case (i) as an example).

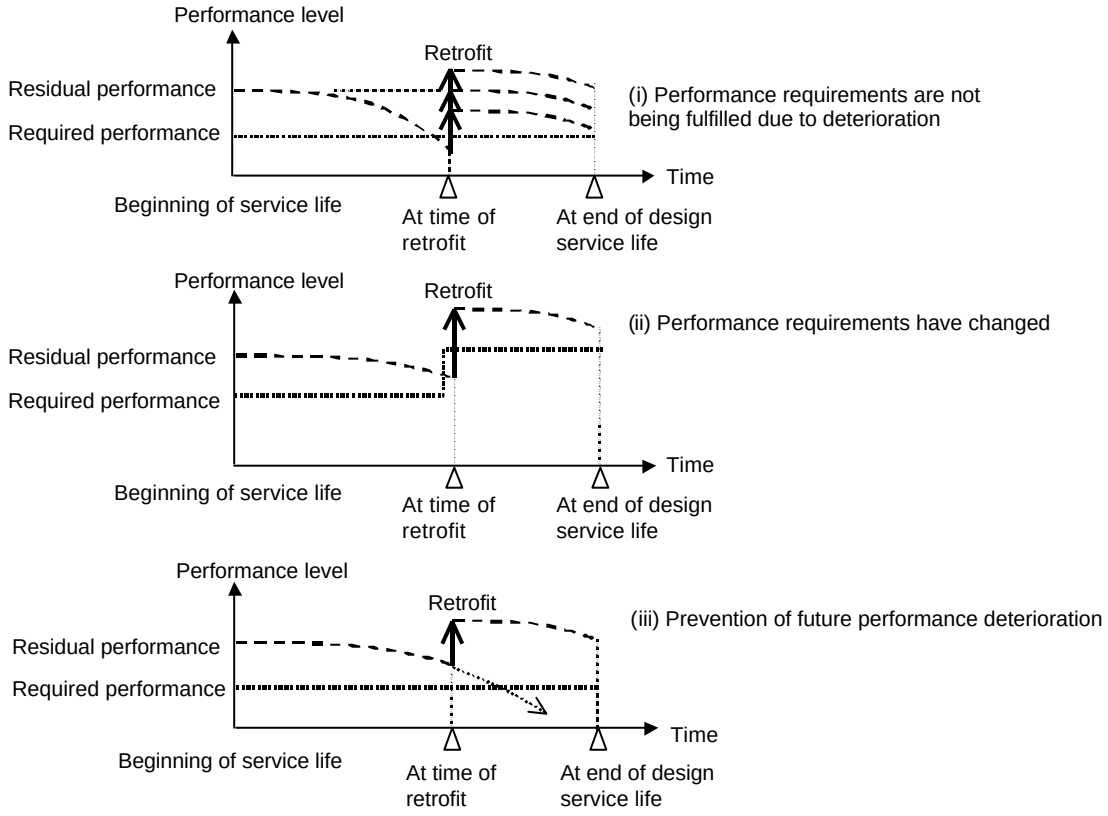


Figure C2.2.2 Performance improvement through retrofitting

(5) A viable retrofitting method is selected in accordance with the type of structure being retrofitted, the use conditions, the type and degree of performance to be improved, and so on. Chapter 7 in these (draft) guidelines covers general matters pertaining to the selection of the retrofitting method, primarily the external cable construction method, bonding and jacketing construction method, and overlaying and jacketing construction method. Design considerations when conducting retrofitting using these construction methods are shown in the retrofitting manuals.

(6) A check is conducted to confirm that the structure retrofitted with the selected retrofitting method will fulfill performance requirements after retrofitting at all points throughout its remaining design service life. Changes over time in the performance of retrofitted structures should be considered in design, in accordance with the principles shown in Section 2.3 in this chapter.

(7) Considerations for construction using the external cable construction method, bonding and jacketing construction method, and overlaying and jacketing construction method are shown in the retrofitting manuals.

2.3 Changes over Time in Performance of Retrofitted Structures

(1) In the design of retrofitted structures, it must be confirmed that the retrofitted structure will fulfill performance requirements after retrofitting at all points throughout its remaining design service life. When the performance requirements remain constant over time, based on the fact that the performance of a structure generally deteriorates over time, verification assuming the end of design service life may be performed in place of overall design life verification.

(2) When the changes over time in the performance of the retrofitted structure during its service life due to load action and environmental action cannot be predicted with sufficient reliability, one of the following methods must be used.

(i) Select retrofitting materials, structural specifications and construction methods such that there will be no decline in the performance of the structure over time in real terms.

(ii) Select retrofitting materials, structural specifications and construction methods such that the decline in performance will only be to the extent predictable with existing prediction technologies.

(iii) Devise measures to conduct maintenance during the service life after retrofitting to ensure that the performance will not go below performance requirements.

[Commentary]

(1) **Figure C2.3.1** shows the ideal manner in which performance verification for retrofitted structures should be performed. During use, the status of the structure (characteristics of materials in the structure, accumulated damage, structural aspects) will change over time due to load action and environmental action. As the performance of a structure at each point in time will be achieved by the result of these factors, the performance exhibited will also change over time. Accordingly, to verify the performance of the structure after retrofitting at a future point in time, ideally the changes experienced by the structure over time under the assumed load action and environmental conditions should be predicted and, based on the results, the performance at the point in time being verified should be evaluated and verified against the performance requirements.

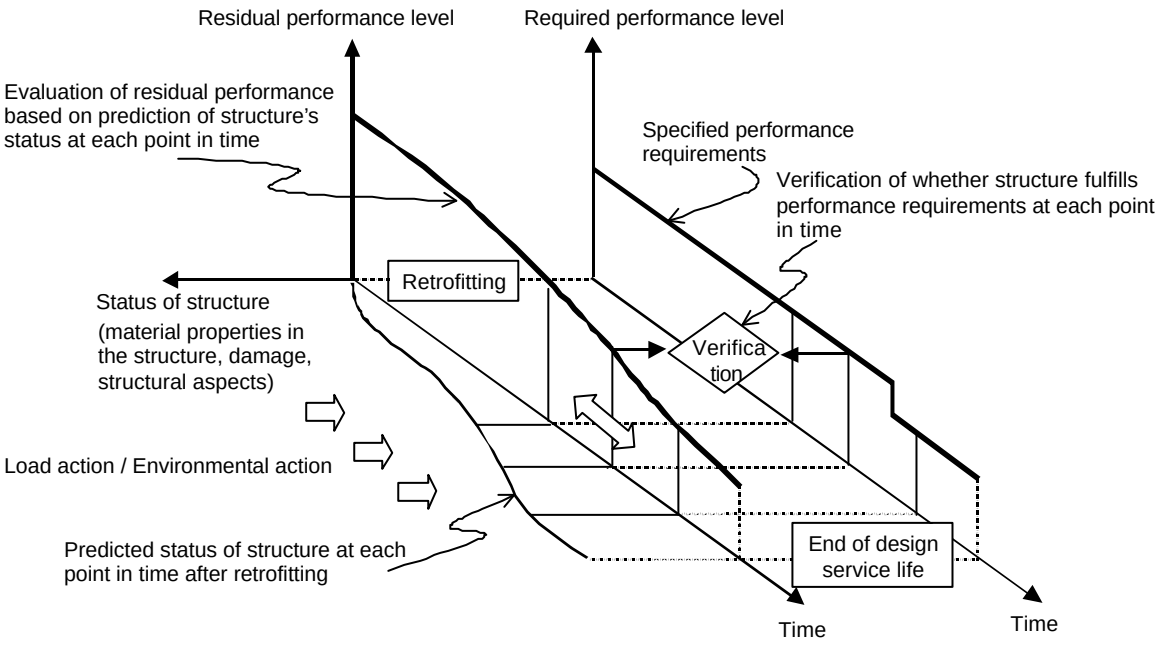
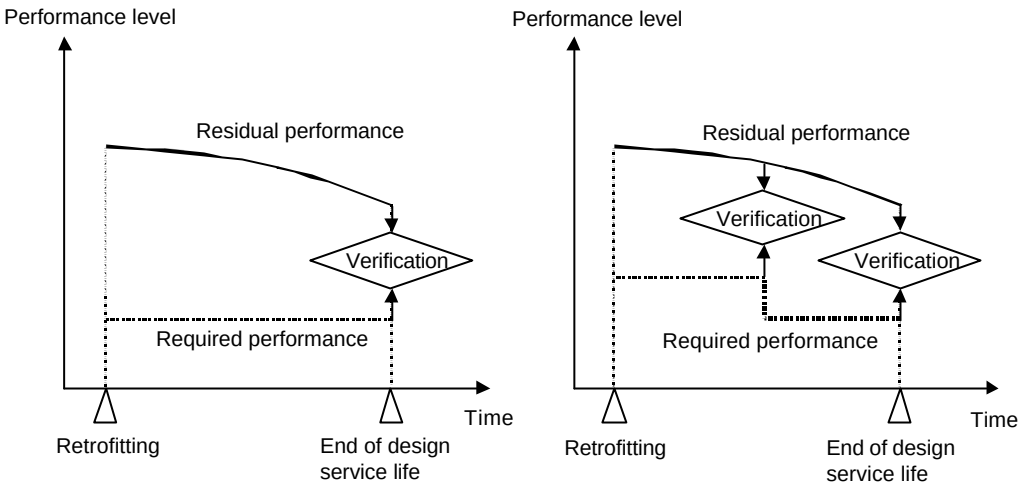


Figure C2.3.1 Performance verification of structure along time axis



(a) When performance requirements are constant over time, verification for the end of the design service life may be performed in place of verification over the entire design service life.

(b) When performance requirements are not constant over time, points for verification sufficient to ensure that performance requirements are fulfilled over the entire design service life must be set.

Figure C2.3.2 Approach to setting verification points for performance of retrofitted structures

When the required level of performance for the structure after retrofitting is constant over time, the performance of the structure at the end of its design service life may be evaluated and fulfillment of performance requirements confirmed rather than performing verification over the entire design service life. This approach uses the fact that the performance of structures generally experiences monotonic decrease over time due to load action and environmental action during use. It cannot be used when performance requirements change over time (see Figure C2.3.2). With this method, it is not necessary to make a minute evaluation of changes over time in the performance of the structure, just the performance at the end of the design service life.

(2) Currently, these are the methods generally used to deal with changes over time in the performance of structures. Considerations relating to materials when these methods are used with the external cable construction method, the bonding and jacketing construction method and the overlaying and jacketing construction method are noted in Chapter 3 of these (draft) guidelines. Considerations relating to design and construction are noted in the retrofitting manuals.