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Structural design of temporary spatial structures

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Abstract

This is a summary of the keynote lecture in the OS "Structural design of temporary spatial structures", organized by IASS WG19. In Chap. 1, temporary spatial structure (TSS) is defined as a structure, which is used for a limited period of time, and the structural safety of which is supported by a safety control system (SCS). And it is introduced that objective of the WG19 is to draw up a guideline for structural design of TSS, and also that the major concerns of the working are a) design load reduction and b) how to design SCS. In the following chapters, major topics corresponding to these issues are reviewed. In Chap.2, ordinary current building regulations are generally described, where it will be noted that structural performance requirements classified into three; 1) serviceability, 2) structural and life safety, 3) secondary damage protection, and in addition, that building regulations tend to prefer to express performances in definitive terms rather than in probabilistic terms. In Chap. 3, structural performance required of TSS is discussed concluding that; (1) Design levels of load can be reduced only when performance requirements in local building regulation is expressed in probabilistic terms, (2) Modifications of required performances can be allowed only when they are written in technical terms, (3) It is recommended at the modification to take structural characteristics of TSS into consideration and in addition to take advantage of SCS, (4) In some cases, it is necessary to add special performance requirement besides those in local building regulation.

Finally in Chap.4, conceptual outline of the structural design guideline for TSS is shown.

Keywords: temporary spatial structure, design guideline, design load reduction.

1. Introduction

Spatial structures such as exposition pavilions, tent shelters after disasters, etc., have been used only for a short period of time. Mostly, design loads for these structures are allowed to assume lower than those for ordinary structures. But grounds for reducing design loads have not always been explained clearly.

In general, spatial structures are light in weight and therefore may have particular characteristics which are not observed in ordinary heavy weight structures. For example, some are easy to assemble or disassemble, some can be easily reinforced in an emergency, some can change their mechanical shapes or properties when necessary, some can afford long evacuation time when they fall down, etc. Most of current structural design guidelines for buildings have been intended to be applied to heavy weight structures, and so they have not taken those characteristics of spatial structures into consideration. If we design spatial structures taking those characteristics into consideration, the market for spatial structures may expand wider.

In this paper, a spatial structure or a part of it will be called a temporary spatial structure (TSS), when it satisfies the conditions below;

1) It is used for a limited period of time, and is not used beyond the period.

2) Its structural safety has been supported by a safety control system (SCS) over the period of use.

Objective of the IASS WG19 is to draw up a guideline for structural design of TSS. The major concerns of the working will be;

a) How the period of use ought to relate the extent of design load reduction?

b) How structural characteristics and SCS ought to be taken into structural design of TSS?

In the following chapters, major topics corresponding to these issues will be reviewed.

2. Structural performances required of ordinary structures in current building regulations

2.1. General description of current building regulations

Table 1 shows examples of performance requirements provided in ordinary building regulations. As shown in the table, performance requirements, in general, are consist of three parts;

1) Designation of loads or load combinations to be adopted in the structural design

2) Designation of design levels for each of the load and load combination

3) Requirements of performance for each of the design levels

The number of design levels designated is, generally, two or three, and they correspond to phenomena of different occurrence probability. Performance requirements, mostly, contain names or locations of all building parts that shall meet the requirements. And, they are, generally, related to any of the three damage types shown below;

a) Damage to services, operations or functions of a building (serviceability)

b) Damage to major structural members and human lives in a building (structural and life safety)

c) Damage to public or private property and human lives outside of a building (secondary damage protection)

For convenience, performances corresponding to the damage type a, b and c will be called as serviceability performance, structural and life safety performance and secondary damage protection performance, respectively, in this paper.

The secondary damage referred to in item c) has been allowed implicitly in building regulations, when it occurs at severest storms, earthquakes, etc., but has not been allowed when it occurs in the event of natural phenomenon of moderate or less intensity, because such damage tends to cause dangers to the normal social/economic activity in the local community. Requirements W2 and E1 in Table 1 correspond to this type of damage.

Table 1: Examples of performance requirements in ordinary building regulations

Load	Design level	Performance requirement
Wind load	2 year recurrence interval	W1; No damage to serviceability
	10 year recurrence interval	W2; No removal of roof and wall cladding
	50 year recurrence interval	W3; Structural frames remain in elastic range
Earthquake load	JMA ground motion intensity IV	E1; No falling-off of exterior walls No breakage in window glass
	JMA ground motion intensity V	E2; Stress in structural members shall not exceed the yield stress of material
	JMA ground motion intensity VI	E3; No collapse

2.2. Expression of design levels in building regulations

Design levels are expressed in two ways; one is the expression in probabilistic terms, and the other is that in definitive terms. In Table 1, “50 year recurrence interval” is an example of the probabilistic expression, and “JMA ground motion intensity V” is an example of the definitive expression. Design levels for wind load and snow load can be expressed in probabilistic terms, but those for earthquake load can not be expressed in probabilistic terms, because earthquake is not a probabilistic phenomenon.

It should be noted that building regulations, in general, tend to prefer definitive expressions rather than probabilistic expressions, because the information on structural performance of buildings is essential for citizens to live safely in the community, and therefore the information has to be written in such a way as most citizens can understand easily.

3. Structural performance required of TSS

3.1. Load and its design levels

When building a TSS, the local community of the building site will require that the TSS should have the same level of structural performance as required of ordinary structures in the community. And, therefore, it will be recommended in the design of TSS to assume the same loads and design levels as those required of ordinary structures.

Every TSS has a definite period of use, and so it is possible to calculate the probability of safety during the period. If the local building regulation requires a structural performance in probabilistic terms, then design loads for TSS can be assumed smaller than those for ordinary structures.

However, as stated in the section 2.2, building code provisions tend to prefer definitive expressions rather than probabilistic expression. When the design levels in the local building regulation are expressed in definitive terms, it will not be allowed to reduce the design levels. In such cases, the design levels assumed for TSS have to be the same as for ordinary structures.

3.2. Performance

In ordinary building regulations, some performance requirements are expressed in technical terms, and some are in general terms. Looking at the Table 1, "W3; Structural frames remain in elastic range" and "E2; Stress in structural members shall not exceed the yield stress of material" are typical examples of the former expression, and "W1; No damage to serviceability" and "E1; No falling-off of exterior walls" are examples of the latter.

Performance requirements expressed in general terms can not afford any interpretation, and, therefore, those requirements have to be adopted without any change in the design of TSS. On the other hand, performance requirements expressed in technical terms can afford interpretation, because the requirements are premised on the assumption that structural systems of buildings are limited in scope and they can not be applied to buildings having structural systems out of the scope. For example, in case of the performance requirement W3, when the TSS has no structural frame, the W3 can be interpreted as "the structure shall not suffer any damage that needs repair to restore". In such cases, it will be recommended to modify the requirements adequately, taking structural characteristics of TSS and the advantage of SCS into consideration.

3.3. Additional consideration for mechanical properties of TSS

Some TSS has special mechanical properties, which may cause very special behavior in hazardous conditions. When structural designer of TSS judges that special attention should be paid on the special behavior, and when the local building regulation has not taken such behavior into consideration, some appropriate measures should be taken about it. Whether such particular attention is necessary or not, has to be judged against each of the three performance requirements, described in section 2.1; serviceability, structural and life safety, and secondary damage protection.

Materials or structural systems used for TSS are often needed to be tested in a TSS in order to confirm their characteristics in the on-site full-scale condition. In such a case, it has to be supposed that unexpected behaviors might occur in hazardous conditions. Such circumstances should also be considered as one of the special mechanical properties of TSS, on which special attention should be paid in the TSS design. The special attention in such cases is, for example, to design a SCS subsystem, which enables at the occurrence of unexpected behavior to prepare some structural countermeasure and, in addition, to organize an emergency support team.

4. Conceptual outline of structural design guideline for TSS

In this chapter, an idea of the basic concept of structural design guideline for TSS will be introduced.

4.1. Scope of application

(1) This guideline applies to structural design of TSS.

(2) TSS can be used changing its location within a certain geographical area.

(3) Where a building regulation applies to TSS, it applies over this guideline.

4.2. Description of TSS

(1) TSS is used for a limited period of time, and is not used beyond the period.

(2) TSS must have and maintain a safety control system (SCS) through the period of use. SCS has to be designed so as to be able to keep a safety level of TSS higher than or equal to that the local community requires of ordinary spatial structures.

(3) SCS to be attached to TSS consists of hardware systems and support teams, which work according to the SCS operation manual. TSS owners shall be responsible for the proper operation of SCS. SCS can be revised, when necessary, not so as to impair the original safety level.

(4) In case that some structural members of TSS have been designed to be replaced at a certain period of time, the structural members must be replaced as scheduled.

(5) When materials or structural systems are planned to be used experimentally in some parts of TSS, SCS has to be designed so as to be able to deal properly with unexpected failure or breakage of those materials or structural systems.

4.3. Loads and design levels

(1) Major loads that TSS has to bear should be assumed as design loads. The design loads shall include all loads that local building regulation requires to take into consideration in the design of spatial structures.

(2) For each design load selected except dead loads, design levels shall be assumed. Design levels have to be decided, in general, in relation to serviceability, structural and life safety, and secondary damage protection. When some combinations of loads may cause critical effects on TSS, design levels shall be decided also for those load combinations.

(3) Design levels can be assumed based on the occurrence probability, when natural phenomena corresponding to the load arises from stochastic process. And, in addition, design levels shall be equal to or higher than those local communities require of ordinary spatial structures.

4.4. Category of loads

(1) Classify loads into two categories;

Category 1: Load, the occurrence time of which can be predicted beforehand, and allows enough time to complete preparation required in SCS, such as wind, snow, etc.

Category 2: Load, the occurrence of which can not be predicted beforehand, or load, the occurrence of which can be predicted beforehand, but do not allow enough time to complete preparation required in SCS, such as earthquake, etc.

(2) Those categories will be referred to herein as "C1" and "C2", respectively.

4.5. General description of SCS

(1) Structural safety of TSS is supported by SCS all over the period of use.

(2) SCS shall be designed to be able to cover all design levels for each load and load combination.

(3) SCS is composed of many subsystems. Each subsystem is a combination of a set of hardware and a support team, which are mobilized at hazardous conditions. (See Table 2)

Table 2; a conceptual example of SCS. L1=serviceability level, L2= secondary damage protection level, L3= structural safety and life safety level

Load	Category	Design levels	SCS subsystems		
			Quantity monitored(*)	Hardware	Support team
Wind	C1	L1=15m/s L2=25m/s L3=40m/s	0-10m/s	none	To
			10-20m/s	W1	Tw1
			20-30m/s	W2	Tw2
			30-40m/s	W3	Tw3
Snow	C1	L1=30cm L2=40cm L3=60cm	0-20cm	none	To
			20-40cm	S1	Ts1
			40-60cm	S2	Ts2
			60cm-	S2	Ts3
Earthquake	C2	L1=20cm/s^2 L2=50cm/s^2 L3=100cm/s^2	-	none	To
			-	none	Te1
			-	none	Te2

(*) Wind speed, snow depth, structural response, etc., monitored for SCS operation.

(4) SCS and TSS's main structural frame have to be designed according to the close functional correlation between them.

(5) In order to operate SCS correctly in the event of category C1 phenomena, the owner of TSS has to monitor the phenomena or the response of TSS. The monitoring has to be carried out, whenever necessary, using any methods that are effective for estimating the present condition of load acting on TSS.

4.6 Design of SCS subsystems against loads classified in category C1

(1) Two, three or more SCS subsystems will be necessary for each load in category C1.

(2) Major subjects to be considered in the design of SCS subsystems are what and how many hardware and persons should be mobilized at every step of load intensity. (See Table 2)

(3) A wide variety of ideas can be applied to SCS subsystems. Followings are examples of useful ideas;

a) Before a load goes up to a certain level, strengthen TSS by adding some structural sub-members to somewhere in the prototype structure, and take them off when the load has reduced enough.

b) In order to avoid any situations that load exceeds a critical level, take such actions as shown below during or before a hazardous condition;

To decrease load (example; to sweep snow drift)

To change structural configuration of TSS (example; inflation of air dome)

c) Before a load goes up to a certain level, evacuate TSS itself to some other place, or disassemble TSS.

4.7 Design of SCS subsystems against loads classified in category C2

SCS subsystems against loads classified in Category C2 shall be either of the followings;

a) Assume design levels of TSS so as to be equal to or higher than those required in the local building regulation. And no SCS subsystem is mobilized.

b) Design roofs and floors of TSS so as to collapse slowly enough to allow persons inside to evacuate safely. SCS subsystem for such structure is recommended to consist of equipments for monitoring the collapse procedure and a support team for the evacuation control.

4.8. Safety control procedures and implementation

(1) All safety control procedures included in SCS shall be written in a safety control manual.

(2) TSS owner shall be responsible to implement all those safety control procedures written in the manual.

(3) TSS owner shall also be responsible to train, periodically, all persons and teams that will be in charge of SCS subsystems.