Activity Summary of JSCE Subcommittee 351
– Integrated methods for design and performance evaluation of concrete structures –

Introduction

The JCSE's Concrete Committee has for decades been carrying out various research works on design and performance verification methods for concrete structures, especially in such areas as seismic performance verification, developing a framework for long-term performance evaluation, implementing design systems that utilize advanced techniques, etc. However, there have been insufficient trials to ensure that the resulting individual engineering/scientific techniques are systematically incorporated into design and performance verification frameworks for concrete structures.

Subcommittee 351 was set up to carry out research aimed at establishing a comprehensive performance evaluation system for new and existing concrete structures by considering the interrelations between behaviors including creep and shrinkage, traffic loading fatigue, environmental deterioration of materials, mechanical external actions and soil-structure interactions. The main issue being investigated by the subcommittee is short- and long-term coupled performance verification/evaluation techniques in time domain, aiming at realization of performance evaluation for concrete structures 'as they are'. The subcommittee had over 40 members from universities, research institutes, construction companies and design consultants, and worked on the above issue for five years (January 2015 – August 2020, except 1 year break).

Working groups and final report

During the first term of the subcommittee (January 2015 – December 2016), four working groups (WGs) were set up on "Soil-structure interaction", "Performance evaluation", "Performance in time domain", and "Engineering applications". In the first report (Concrete Engineering Series 113), the problems needing to be solved to achieve a unified performance evaluation framework were summarized. Later, based on the findings of this report, the subcommittee continued for a second term (January 2018 – August 2020) during which the work of finding solutions to the problems and developing the framework was advanced. The WGs were then restructured into four groups ("Underground structures", "Rigid frame structures", "Bridges", and "Engineering applications") and a final report (Concrete Engineering Series 125) was published based on the results of their activities. This final report,

Table 1 Contents of final report

Volume 1:	**Overview of activities in subcommittee**
Volume 2:	**Design**
Volume 3:	**Future vision of performance evaluation by integrated method**
PART A:	Timeline of structures
PART B:	Performance verification of rigid frame structures in four-dimensions
PART C:	Performance verification of RC bridge deck slabs in four-dimensions
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Volume 4:	**Structures**
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PART B:	Rationalization of underground structures
PART C:	Investigation on performance of GRS bridges
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Volume 5:	**Members and materials**
PART A:	Performance of highway bridge slabs under cyclic and environmental actions
PART B:	Performance evaluations of RC members by material nonlinear 3D FEM
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PART D:	Integrated investigation on structural performance based on material science
Appendix	

which runs to over 550 pages and includes the valuable new and improved results obtained by the WGs, presents a future vision of lifetime performance evaluation and design for concrete structures in the time domain. The table of contents of this report is given in **Table 1**.

Activity overview of subcommittees

The "Underground structures" WG investigated the seamless integration of temperature stress analysis during construction with performance verification under service conditions for the case of an underground RC box culvert. Additionally, a trial of integrated time-domain analysis of the structure was carried out, including consideration of construction procedures, cement hydration and concrete strength development, initial stress state due to temperature stress, structural behavior under service loading, and seismic response. Meanwhile, the "Rigid frame structures" WG analyzed the fracture mechanism and the influence of non-structural members and long-term shrinkage on the performance of RC rigid frame viaducts, aiming at further improvement of performance evaluation techniques in four dimensions (3D space plus time).

The "Bridges" WG took on the seamless integration of material design and structural design for slab decks, undertaking analysis of damage in RC/PC slabs under moving loads and investigations into structural details and effective strengthening methods. Additionally, the WG carried out various investigations on GRS (Geosynthetic- Reinforced Soil) bridges using a combination of the reinforced soil abutment with the concrete culvert. The "Engineering application" WG discussed a near-future total performance evaluation system covering design-construction- maintenance based on results provided by the other three WGs. Engineering techniques that would contribute to such a system were extracted, with feedback given to the three WGs. Finally, based on sophisticated numerical analysis, a Structure Lifecycle Timeline (**Fig. 1**) was developed, along with a movie that visually explains the lifetime of a structure.

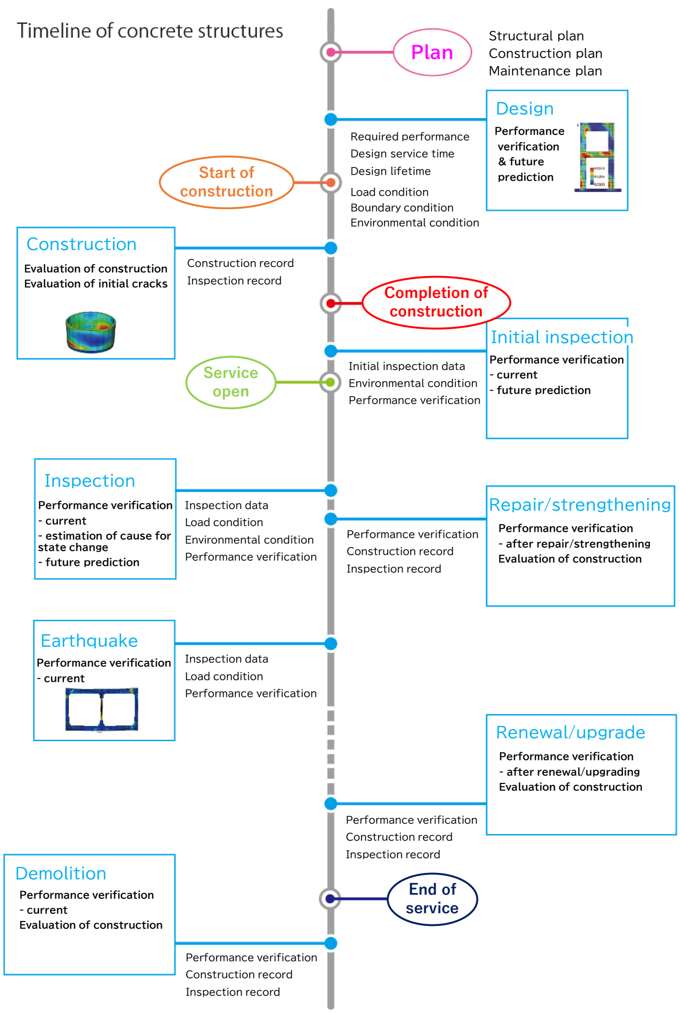

Fig.1 Concrete structure lifecycle timeline

Future vision of performance evaluation

In recent times, digital techniques have been progressively applied in various engineering fields, including civil engineering. Realization of the "Society 5.0" initiative, promotion of "i-construction" and the implementation of quantum computers along with similar advancements may bring a rationalization of design-construction-maintenance into a total system for social infrastructure.

Furthermore, there have already been some trial applications of the “Smart City” concept and “Digital Twin” technology, where real structures and their cyberspace counterparts are linked to each other in real time. Data that, so far, has been utilized in analog format only within each closed field and organization, is generally being opened up worldwide and made available in digital data format. Progress in computing, data communications and numerical simulation techniques has also been remarkable over the past few years and rapid numerical calculation of huge models is now a possibility. Simulation methods for entire concrete structures, such as the multi-scale multi-physics finite element method, are being developed, and the behavior of real structures can now be evaluated ‘as they are’ without simplification.

Based on this background and the current state of society, there is an urgent need for a paradigm shift in which such progressive digital numerical simulation techniques are effectively used in the design, performance verification and maintenance of the social infrastructure. That is, it is necessary to rebuild the operational framework for social infrastructure to make the best use of up-to-date tools and methods. With regard to numerical calculations (such as the finite element method), *ad hoc* implementation of huge complex models may result in manual model preparation and data processing becoming bottlenecks in the system. Thus, fully- or semi-automated processing schemes are essential, incorporating tacit knowledge, various data fed back from inspections, and the expertise of engineers specializing in numerical analysis. The role of numerical simulations, in principle, is to provide useful information that enables engineers to judge the performance of a structure, hopefully through straightforward automated procedures.

Numerical simulation methods have an affinity with and a similarity to the concept of lifetime tracking of structures, which means directly evaluating structural response in the time domain as a combination of material and structural behaviors. Improvements in these techniques have been driven by great efforts on the part of many engineers and researchers over decades. By applying such methods, it is now becoming possible to evaluate the response time history of structures modeled ‘as they are’ under the influence of various combinations of external actions (**Fig. 2**). The next task for engineers is to establish an integrated system for the utilization of such methods, as in the title of this subcommittee. In other words, on the premise of integrating various digital information techniques (such as big data, high performance computing, and artificial intelligence), it is our future vision that the lifetime of structures will come to be quantitatively evaluated on an engineering basis (**Fig. 3**).

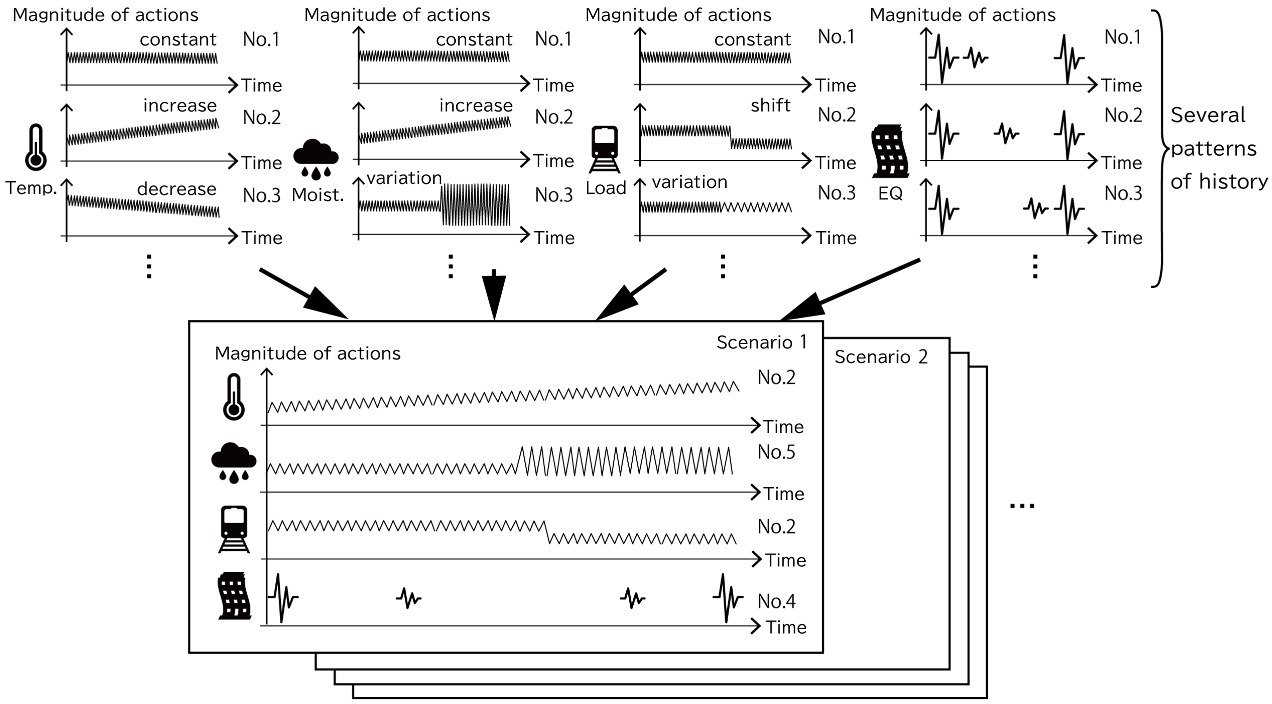

Fig. 2 Various time histories of external actions and scenarios

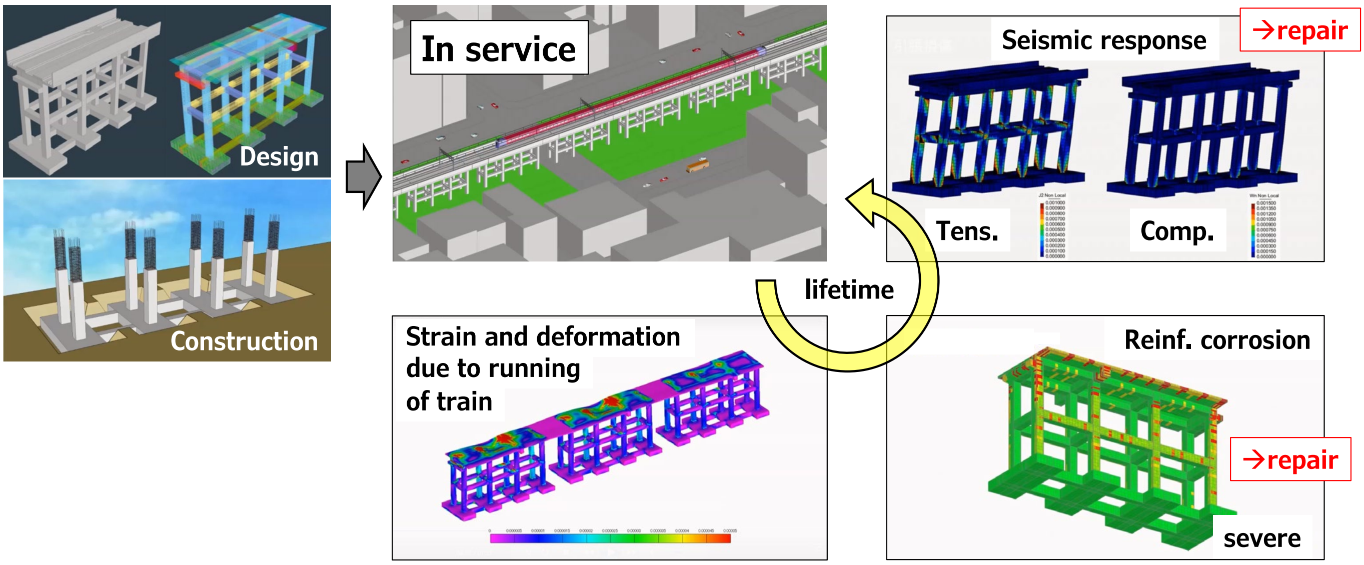

Fig. 3 Our future vision: lifetime simulation of concrete structures