Committee Report: JCI- TC202A

Technical Committee on Verification & Validation (V&V) in Structural and Durability Simulations of Concrete Structures

Naoshi UEDA, Shinichiro OKAZAKI, Mao KURUMATANI, Toshihide SAKA and Hiroki OGURA

Abstract

In this technical committee, we investigate the applicability and issues about the Verification & Validation (V&V) of simulations conducted in the field of concrete engineering. To this end, we presented some examples of common analyses aimed at implementing V&V and the content discussed within the committee. Further, we introduced results of benchmark experiments of RC beams with various parameters on the mechanical behavior. Moreover, we summarized the current status and problems related to the durability simulation.

Keywords: Verification & validation, code verification, solution verification, uncertainty evaluation, benchmark experiment

1. Introduction

In the field of concrete engineering, many simulations have been conducted to evaluate the mechanical behavior and deterioration phenomenon of concrete structures. Several technical committees have been established in this society, Japan Concrete Institute, and relevant activities have been conducted proactively [1]. However, there is no clarity on the current validation method for the simulation results up to now. General-purpose simulation codes have become widespread, and it has become easy to handle simulations such as finite element analysis; however, models and computational processes that are used in such simulations are becoming black boxes. Incorrect results might be adopted in the design if an engineer does not understand the characteristics and scope of application of the model. Such cases can lead to a serious accident such as destruction during construction or during the service of civil engineering / building structures[2].

Meanwhile, only the experimental results are often recognized as the truth when simulation results differ from those of experiments, and the simulation sometimes can be recognized as inadequate. Concrete is a composite material, and therefore, its behavior has variability in material level and boundary conditions and experimental results include various uncertainties in structural experiments. Thus, the results may vary greatly even in structural experiments[3]. However, the evaluation methods of experiments themselves that include a variety of variations have not been systematically organized.

Global organizations such as the International Association for the Engineering Modelling, Analysis and Simulation Community (formerly National Agency for Finite Element Methods and Standards, NAFEMS) in the U.K. and the American Society of Mechanical Engineers (ASME) in the United States have indicated the importance of problems related to evaluation methods of experimental values that include a variety of variations; they are developing strategic efforts for the international standardization of simulation-quality verification methods.

In Japan, various academic societies such as the Japan Society of Mechanical Engineers and Atomic Energy Society of Japan have been discussing verification and validation (V&V) of simulations . For concrete engineering, Standard Specifications for Concrete Structures published by the Japan Society of Civil Engineers describes realistic discussions for practical use, e.g., checking methods that use nonlinear analysis methods[4]. However, despite such discussions, there is a lack of an objective index or methodology for validating simulations. This is left to the engineering expertise of the analyst, and in some cases, the simulation is validated through certification[5].

Given this background, this technical committee, which includes the FS committee, has been active since three years for clarifying the methodology and issues of V&V of simulations related to concrete structures and materials. **Table 1** lists the members of the committee. Activities in this technical committee are conducted across four WGs: Structural Analysis WG (chief, Toshihide Saka), Experiment WG (chief, Hiroki Ogura), Guidance WG (chief, Mao Kurumatani), and Materials WG (chief, Shinichiro Okazaki). In the Structural Analysis WG, we conduct a common analysis on bending failure and shear failure of reinforced concrete (RC) beams and discuss specific V&V methods. In the Experiment WG, we conduct benchmark experiments to quantify the variability of the results generated in the structural experiments and to organize the uncertainties. In the Guidance WG, we summarize the implementation guide for V&V based on the results of the Structural Analysis WG and Experiment WG. In the Materials WG, we summarize the status and problems, and we discuss the need for V&V in applicable simulations. In this report, we introduce some of these results.

Table 1: Committee Members

Chairman of Committee	Naoshi UEDA	Kansai University
Secretary general of Committee	Shinichiro OKAZAKI	Kagawa University
Secretary of Committee	Mao KURUMATANI	Ibaraki University
	Toshihide SAKA	Kajima Corporation
	Masayuki TSUKAGOSHI	Fukuoka University
	Yoshihito YAMAMOTO	Hosei University
Committee members	Go IGARASHI	The University of Tokyo
	Tsuyoshi ICHIMURA	Earthquake Research Institute, University of Tokyo
	Hiroki OGURA	Shimizu Corporation
	Kazuhiro KAWAGUCHI	JIP Techno Science Corporation
	Kiyofumi KURUMISAWA	Hokkaido University
	Atsushi FUJIMOTO	ITOCHU Techno-Solutions Corporation
	Kenichi FUCHIZAWA	JIP Techno Science Corporation
	Takuzo YAMASHITA	National Research Institute for Earth Science and Disaster Resilience
Adviser of Committee	Riki HONDA	The University of Tokyo

2. Overview and flow process of ASME V&V 10

In this committee, we investigated the V&V of concrete structure simulations while referencing the V&V 10 published by ASME. The ASME published its guideline6) in 2016 under the name ASME V&V 10, and they published its standard7) in 2019. The ASME V&V 10 seeks to evaluate the prediction performance of "models" used in engineering simulations in the field of computational solid mechanics objectively, and to present its concepts and procedures. The V&V that evaluates the predictive performance of a model is called a "model V&V." We explain the overview and flow process of the model V&V based on ASME V&V 10.

2.1 Overview of ASME V&V 10

First, we briefly explain the keywords "model," "verification," and "validation" used in ASME V&V 10 (model V&V). A "model" is defined as a conceptual, mathematical, or numerical expression introduced to reproduce a physical phenomenon; it includes governing equations, geometric conditions, initial/boundary conditions, load conditions, constitutive laws, numerical solution algorithms, etc. A definite model is constructed based on the prediction target, intended use, and accuracy requirements of the model; the model V&V is an effort to evaluate the predictive ability of that model. Within these efforts, verification is defined as the process of confirming, "is this model being used appropriately?", and validation is the process of confirming, "is this model appropriately predicting physical phenomena?"

Verification includes the following two stages: "code verification," which confirms that the model is being implemented correctly, and "calculation verification," which confirms that the discretization error and numerical error of the model are sufficiently small. Code verification is often implemented by illustrating the reproducibility of theoretical and analytical solutions, and calculation verification is often implemented by showing the grid convergence of numerical solutions that accompany the subdivision of the analysis mesh.

Validation involves the process of comparing the simulation results with the experimental results to confirm that the model can correctly reproduce actual behavior. The predictive ability of a model is evaluated by conducting simulations using a verified model and validation experiment, and after quantifying various uncertainties in both simulation and experiments. If the validation determines that the predictive power of the model is low and the verification is not sufficiently conducted, it will not be possible to distinguish whether the cause is a discretization or numerical error of the model, or the expressive ability of the model.

Thus, the overview (objective) of the ASME V&V 10 can be summarized in brief as "to evaluate the predictive performance of a model for the intended use by verifying that the discretization error and numerical error included in the simulation are sufficiently small, and then by quantitatively comparing the results of both simulations and experiments considering the uncertainties of both simulations and experiments".

2.2 ASME V&V 10 flow process

Fig. 1 shows the flow process of the model V&V based on ASME V&V 10. First, the response value, intended use (IU), and accuracy requirement to be focused on in the prediction target of the model are set. One example of this is to "predict the maximum load of a reinforced concrete beam subjected to four-point loading and the deflection at the center position of the beam with an error of less than 15%”. The ASME V&V 10 positions the definition of IU as the start of V&V, and the model’s predictive ability is validated for the IU.

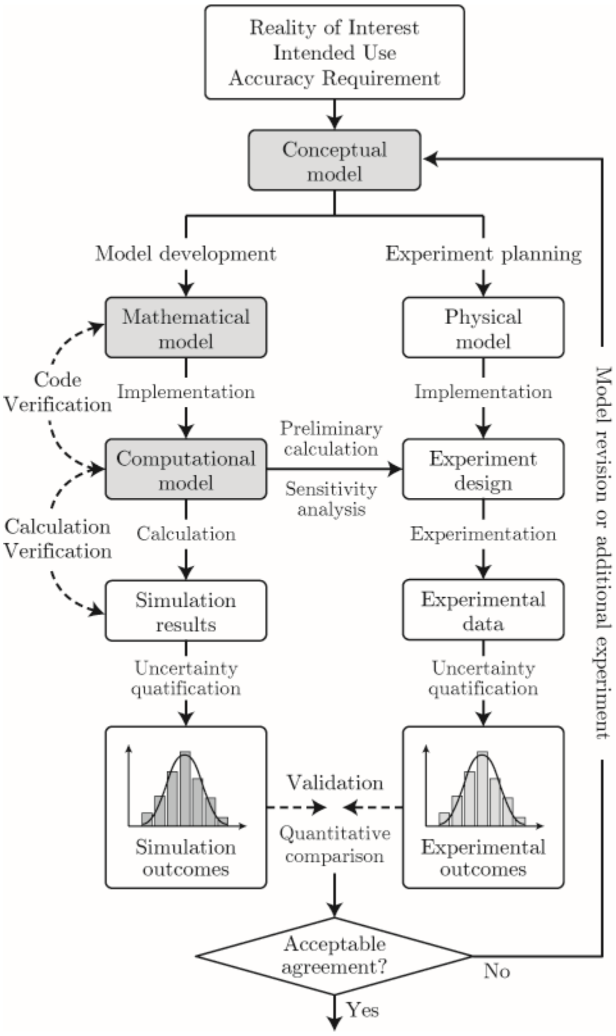


Fig. 1: Flowchart of Model V&V based on ASME V&V 10 [8)]

For the “conceptual model,” behaviors with a high degree of influence that need to be reflected in the model and behaviors with a low degree of influence that can be ignored are identified; the physical phenomenon is idealized (simplified). After examining the conceptual model, this process is divided into model development on the left side and an experimental plan on the right side, with the investigations conducted on each side toward validation. We describe the main points of each item from the model development side below.

A “mathematical model” is a mathematical expression of a conceptual model. In solid mechanics, there are equilibrium equations (static), equations of motion (dynamic), various conservation equations, constitutive equations, load/constraint equations, friction/contact equations, and so on.

A “computational model” is implemented on a computer so that the mathematical model can be solved by numerical analysis; it includes discretization methods such as the finite element method and difference method, in addition to algorithms for solving nonlinear equations. The response value obtained from the computational model is the output value of the idealized “model,” and therefore, it can objectively interpret that the computational result requires a sufficient understanding of not only the computational model but also the conceptual and mathematical models that are the basis of the computational result.

The two stages of verification implemented in model development include “code verification” and “calculation verification.” Code verification confirms that the model is implemented correctly. If the model is implemented correctly, numerical solutions obtained from the computational model can reproduce the theoretical and analytical solutions represented by the mathematical model. Thus, code verification is located between the mathematical and computational models, as shown in Fig. 1. The calculation verification involves the estimation of the numerical error and discretization error of the model. The simulation results and experimental results are compared after verifying that these errors are sufficiently small. Thus, calculation verification is located between the simulation result and computational model in Fig. 1.

Finally, validation is performed by quantitatively comparing the computational results of the verified model with the experimental results. During validation, uncertainties in both the simulation and experiment need to be quantified; for example, the variation in dimensions and material properties, initial/boundary conditions, load conditions, measurement error, and experimental method; those uncertainties need to be compared. An example of quantitative comparison in validation includes a method where the cumulative distribution curve of the occurrence frequency is obtained from the experimental and computational results that have an average and standard deviation and by using the areas surrounded by the curves as the error index9).

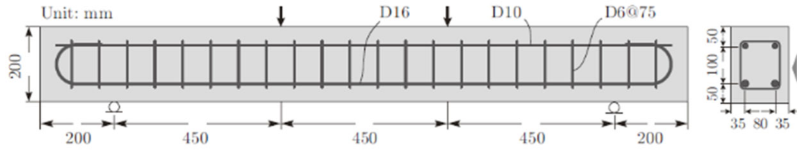
3. Investigation of V&V in structure simulations

3.1 Objective

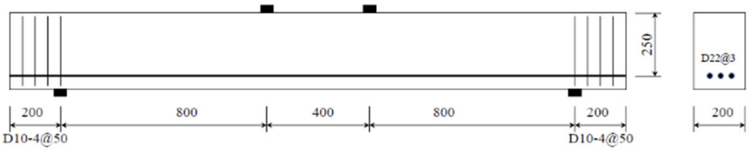
We attempted to apply the V&V procedure shown in the ASME V&V 106,7) to a simulation of RC members for improving the reliability of the numerical analysis results of RC structures and for applying the nonlinear analysis technique of RC structures.

3.2 Overview

A trial application of ASME V&V 10 was executed using the bending fracture and shear fracture of RC beams loaded at four points as examples. We worked on identifying issues when applying ASME V&V 10 to the nonlinear analysis of RC. **Fig. 2** shows the outline of the target specimens.



(a) Flexural failure type[3)]



ad3（a/d=3.2、pt=2.32%、pw=0%）

(b) Shear failure type

Fig. 2: Outline of RC beams

The participating organizations and submitted results are summarized in **Table 2**. Not all institutions can implement all ASME V&V 10 flow processes. Institution B can implement both verification and validation of the bending fracture example. In addition, institutions A, C, D, and F participated in the V&V of the bending fracture example, and they could partially submit the results. For example, solution verification by institutions D and F was conducted up to the linear problem, and the implementation method of the solution verification for nonlinear analysis remained an issue.

As an example of shear failure, there were no equivalents to the theoretical solution referred to in the code verification, and therefore, it was difficult to implement the code verification. Furthermore, solution verification was not implemented in any institution. Sensitivity analysis was implemented in institutions A, C, and D. Uncertainty quantification was conducted in institutions A and D.

Table 2: Summarize of participating organizations and submitted results

Organization			A	B	C	D	E	F	G
Software			SM	SM	SM	Diana	IM	IM	IM
Flexural failure type	Verification	Code verification	○	○10)		○		○	
		Solution verification		○10)		△ Linear		△ Linear	
		Sensitive analysis		○11)	○12)	○	○		
	Validation	Uncertainty Quantification	○	○11)	○12)			○13)	
Shear failure type	Verification	Code verification							
		Solution verification							
		Sensitive analysis	○		○	○			○
	Validation	Uncertainty Quantification	○			○			

* SM: Self-made, IM: Internal Manufacturing.

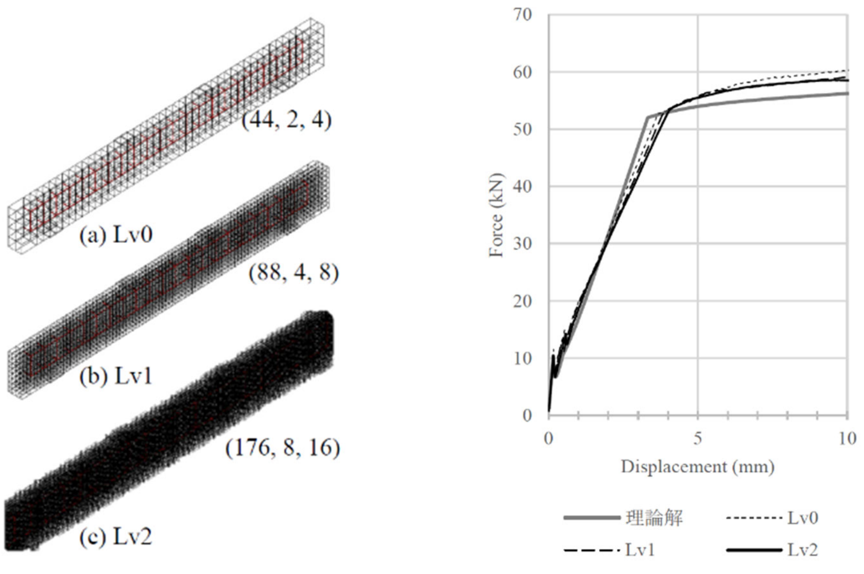
3.3 Example of application of RC beam undergoing bending failure

We briefly introduce an example of the application to a RC beam that undergoes bending failure among the proposed results. The evaluation of the maximum load is set as the IU.

Table 3 presents a list of phenomena that can affect the bending yield strength created by institution C12). **Fig. 3** shows an example of code verification implemented by institution F. Here, the theoretical solution of the load–displacement relationship of the RC beam that undergoes bending failure shown in reference 3) is compared with the numerical solution of the RC beam modeled using a FEM. The load of the first crack is the same regardless of the fineness of the mesh. Furthermore, the yield load of the beam is on line with the theoretical solution, and it can be interpreted that the model is implemented correctly.

Table 3: An example of phenomena identification on flexural capacity of RC beams [12)]

Phenomena		Importance for analytical purpose		Reliability of model
		Maximum load	Deflection at maximum load	
Material	Elastic deformation	High	High	High
	Tensile fracture of concrete	High	High	High
	Tension softening of concrete	High	High	High
	Shear transfer on crack surface of concrete	Medium	Medium	High
	Bond property between concrete and rebar	Medium	High	High
	Elastic-plastic response of rebar	High	High	High
	Dowel action of rebar	Low	Low	Low
	Compression softening of concrete	High	High	Medium
	Reduction of compressive strength due to cracking of concrete	Medium	Medium	Medium
	Confinement effect of concrete	Medium	Medium	Medium
	Buckling of rebar	Low	Low	N/A
Geometry condition	Specimen dimension	High	High	High
	Rebar position	High	High	High
Boundary condition	Misalignment of loading points and supports	High	High	High
	Friction between loading plates and specimen	High	High	Low



(a) Analytical meshes (b) Load displacement relationships

Fig. 3: Examples of code verification for flexural failure of RC beams

Fig. 4 shows an example of the mesh in the solution verification conducted by the institution. In this solution verification, a discretization error is quantified by the analysis of variance, wherein factors that influence the analysis results are selected and the degree of influence of each factor as a variance component is determined by performing an analysis of multiple cases10).

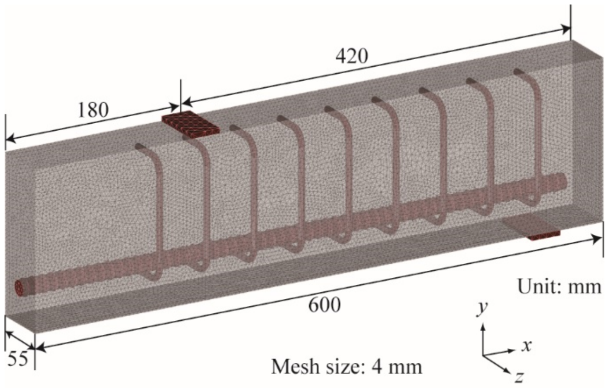
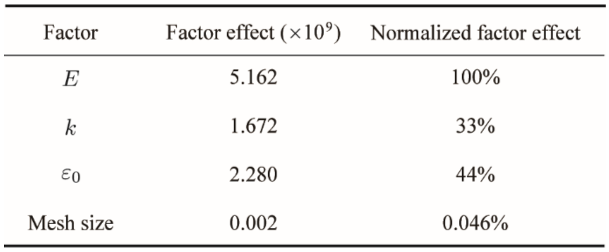


Fig. 4: An example of analytical mesh (symmetry model, quoter) 10)

Table 4 summarizes the results. Compared to Young's modulus, which has the greatest influence, the mesh size influence is 0.046%10), and this confirms that the mesh size influence is sufficiently close.

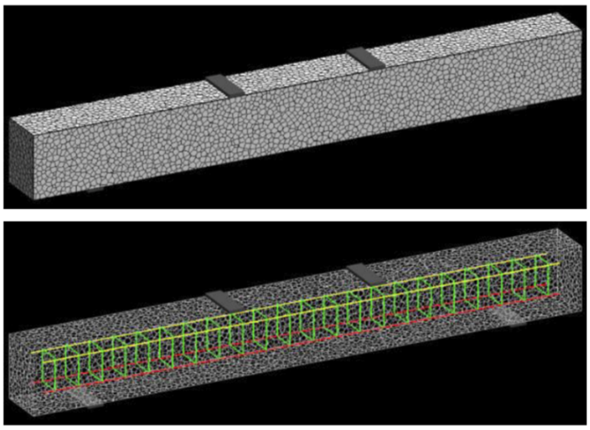
Table 4: An example of solution verification for RC beams failed in flexure 12)



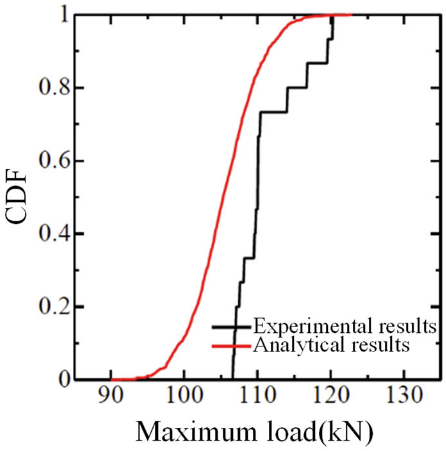
Factor	Factor effect ($\times 10^9$)	Normalized factor effect
E	5.162	100%
k	1.672	33%
ε_0	2.280	44%
Mesh size	0.002	0.046%

Fig. 5 shows the results of an uncertainty quantification conducted by Institution C. In this model, sensitivity analysis is conducted using the compressive strength of concrete, yield strength of reinforcing bars, and effective height as parameters. A surrogate model is created from the results of sensitivity analysis using a linear multiple regression equation; the cumulative distribution is calculated by Monte Carlo simulations12).

Thus, we confirmed that a one-through implementation of the ASME V&V 10 can be conducted for the bending fracture example.



(a) Analytical mesh



(b) Comparison of cumulative distributions between experiment and analysis

Fig. 5: An example of uncertainty qualification for RC beams failed in flexure 10)

3.4 Examples of issues discussed

We provide excerpts from the discussions conducted by the committee on issues when applying ASME V&V 10 to RC nonlinear analysis. In terms of verification, code verification is considered an easy approach when there is a theoretical solution; however, it is unclear how to conduct code verification for problems that have no theoretical solution. Methods using creative solutions14) have been proposed in other fields, but the discussion has not matured sufficiently.

The discretization error needs to be quantified for solution verification; however, it is unclear how to quantify the discretization error of the response amount of interest in a nonlinear analysis. In the linear problem shown by ASME V&V 10, the discretization error is quantified by the lattice convergence, but it is unclear if the lattice convergence can be evaluated by nonlinear analysis. In the structural analysis of concrete, localization and softening behaviors are incorporated into the constitutive law as dimensional average behaviors, and therefore, there is a problem of element dimensional dependence on the response. Further discussions are required for both these points.

Methods such as Monte Carlo simulations can be selected for analysis when quantifying the uncertainty required for validation. A large number of specimens is rarely prepared for a general RC experiment even though there is a need for evaluating the variation among a large number of specimens in experiments. Further, it becomes virtually impossible to prepare a large number of specimens and conduct experiments as their scale approaches that of an actual structure.

Furthermore, although it was possible to conduct the V&V flow process as shown in Section 3.3 for laboratory-level experiments, there is a need to confirm whether similar studies can be conducted on actual structures. We adopted modeling with small element dimensions to minimize the influence of the mesh. Massive computational resources will be required to investigate actual structures with similar element dimensions, and thus, there is a need to investigate acceptable element dimensions.

As described above, we showed an example of a one-through implementation of the ASME V&V 10 flow process. This method is not always universal, and we believe that further research is required.

This committee discussed the ideal approach and contents of V&V guidance in concrete simulations based on findings obtained from the above studies. We plan to publish a V&V guide that summarizes these results in the future.

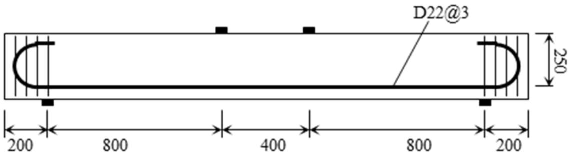
4. Investigation of variation in the structural experiments of RC beams

4.1 Purpose and overview of experiments

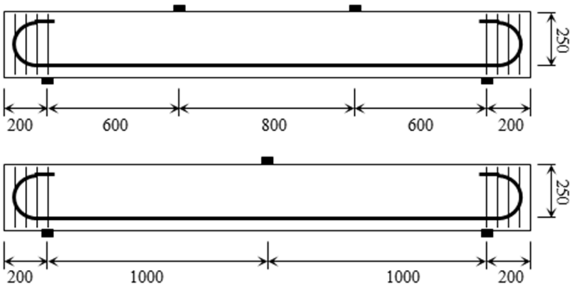
The structural behavior of RC beams is known to vary. Various factors can cause the experimental results vary; for example, environmental conditions of the specimen until loading (effect of dry shrinkage) and differences in testing machines (loading method and boundary conditions). However, such conditions are not clearly described in published papers. Furthermore, it is desirable to have experimental results with little uncertainty and small variation when validating simulation results.

Therefore, we conducted a series loading test on thirty RC beams with clear boundary conditions and loading conditions and to collect experimental results that serve as a benchmark for V&V. The experimental factors included the age and environmental conditions before loading, shear-span ratio (a/d), and amount of shear reinforcing bars.

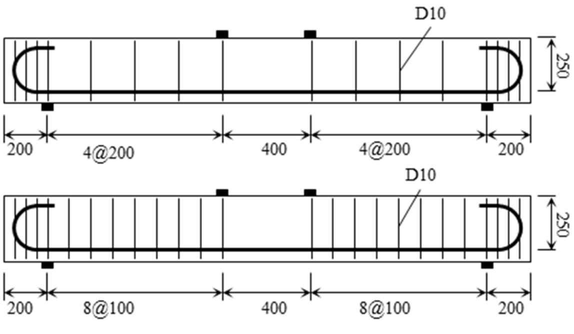
Fig. 6 shows an overview of the RC beams. The specimens are designed as single reinforcement RC beam with a reinforcement ratio of 2.32 in which three D22s are placed at a position with an effective depth of 250 mm and width of 200 mm. Specimens with a shear-span length of 800 mm (shear span to effective depth ratio, a/d is 3.2) is used as the basic specimen, and the influence of differences in the material age and testing institution is investigated. Furthermore, we investigate the influence of a/d in two cases in which the loading point position is changed (a/d of 2.4 and 4.0), and the influence of the amount of shear reinforcement in two cases in which the closed stirrup of D10 is arranged as the shear reinforcement (shear reinforcement ratio of 0.36 and 0.72).



(a) Basic specimen (a/d=3.2）



(b) Influence of shear span to effective depth ratio, a/d (upper: a/d=2.4, lower :a/d=4.0)



(c) Influence of stirrup ratio (upper: 0.36%, lower :0.72%)

Fig. 6: Overview of RC beams

Table 5 summarizes the multiple specimens prepared for each experimental factor; further, it indicates that loading is conducted at four different institutions. All specimens are manufactured in one factory, covered with a sheet outdoors, left to cure for approximately 1–2 months, and then transported to each institution. The loading material age is around 350 days for institution A; around 270 days, institution B; around 60 days, institution C; and around 300 days, institution D.

Table 5: Experimental factors and specimen numbers

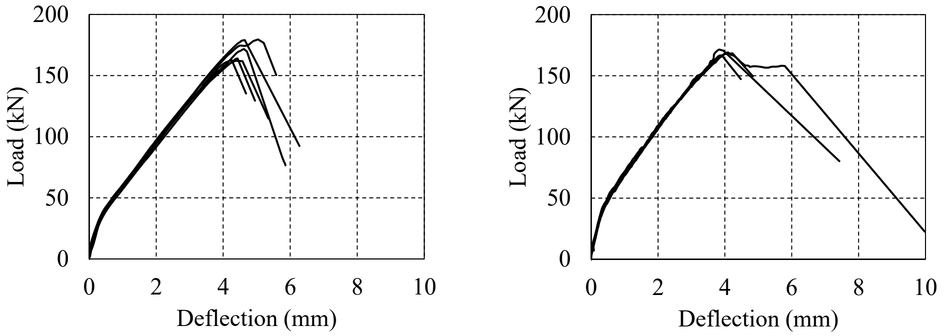
Institutions	Basic specimen	shear span to effective depth ratio		stirrup ratio	
	a/d=3.2	a/d=2.4	a/d=4.0	0.36%	0.72%
A	6				
B	8				
C	5	5	5	5	
D-1	6				
D-2	5			5	5
Sum	30	5	5	10	5

The followings are curing conditions for the specimens until the test at each institution. At institution A, all six specimens are stored outdoors with a polyethylene sheet cover. At institution B, four specimens are stored outdoors with a polyethylene sheet cover, and the remaining four are exposed; all specimens are stored outdoors. At Institutions C and D, the specimens are stored indoors until loading.

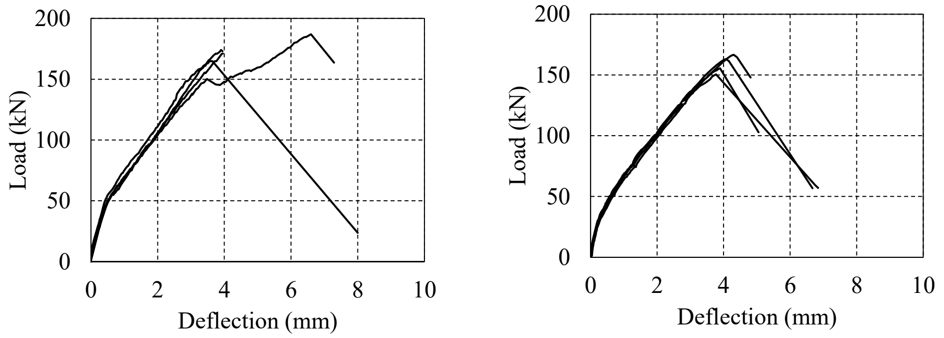
The results of the material tests conducted at each institution indicate that the average values (coefficient of variation) of compressive strength are as follows: institution A, 41.5 N/mm^2 (5.8%); institution B, 49.4 N/mm^2 (2.9%); institution C, 44.4 N/mm^2 (2.3%); institution C (outdoor exposure), 44.6 N/mm^2 (3.5%); institution D-1, 37.7 N/mm^2 (4.9%); and institution D-2, 37.7 N/mm^2 (12.1%).

4.2 Impact of different testing institutions (basic specimens)

The experimental results of the basic specimens conducted at institutions A, B, and C are shown as an example. **Fig. 7** shows the load deflection relationships obtained at each institution. All but one specimen in institution B formed diagonal cracks at a load of around 150 kN; the failure mode in all cases was a diagonal shear failure.



(a) Institution A **(b) Institution B(inner place)**



(c) Institution B(outdoor exposure) **(d) Institution C**

Fig. 7: Load deflection relationships for basic specimens

Table 6 shows a list of the experimental results of each specimen. The average values (coefficient of variation) of bending stiffness after bending cracks, maximum load and deflection at maximum load for the results of the 19 specimens were as follows: 35.5 kN/mm (5.2%), 167 kN (4.8%), and 4.05 mm (7.9%), respectively. The magnitude of the coefficient of variation were almost the same with the material tests mentioned previously, and small when compared to those of previous research$^{3)}$. Thus, these experiments achieved extremely high accuracy.

Table 6: List of experimental results

Specimen	bending stiffness (kN/mm)	Maximum load (kN)	Deflection at Maximum load (mm)
A-1	34.9	163	4.02
A-2	35.6	179	4.50
A-3	34.0	162	4.22
A-4	34.5	172	4.42
A-5	35.4	164	4.22
A-6	35.8	180	4.82
B-1	36.7	169	4.10
B-2	35.6	167	3.85
B-3	37.7	172	3.82
B-4*1	37.0	168	4.10
B-5*1	39.3	174	3.90
B-6*1	39.6	165	3.56
B-7*1	32.6	171	3.96
B-8*1	34.2	150*2	3.48*2
C-1	34.8	151	3.77
C-2	33.5	155	3.89
C-3	—*3	173	—*3
C-4	34.0	167	4.30
C-5	34.6	163	4.07
Average	35.5	167	4.05
C.V	5.2%	4.8%	7.9%

*1: Outdoor exposure, *2: First peak

*3 : Data were not obtained due to instrument error.

4.3 Impact of shear span to effective depth ratio

Fig. 8 shows the loading results. All specimens exhibit shear failure before rebar yielding. The initial stiffness and stiffness after the formation of cracks showed little variation in all cases. The average values (coefficient of variation) of the maximum loads are a/d = 2.4, 226 kN (16.3%); a/d = 3.2, 159 kN (3.9%); and a/d = 4.0, 163 kN (4.8%).

Fig. 9 shows example of crack patterns for each shear span to effective depth ratio. The bending crack formation interval is almost constant regardless of the shear-span ratio. The angles of shear cracks tend to differ for each case. The variation in cracking conditions is small among the five specimens in the same case.

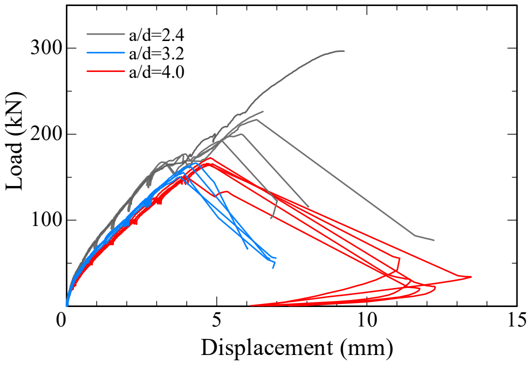


Fig. 8: Load displacement relationships for each shear span to effective depth ratio

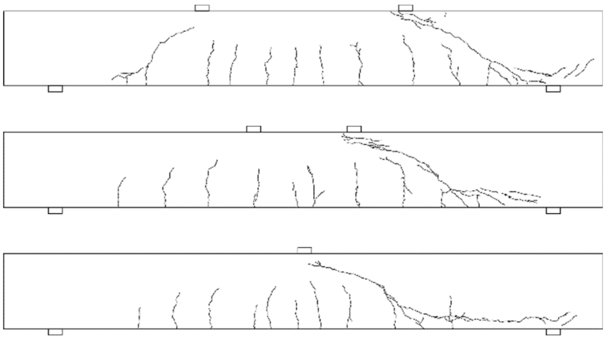
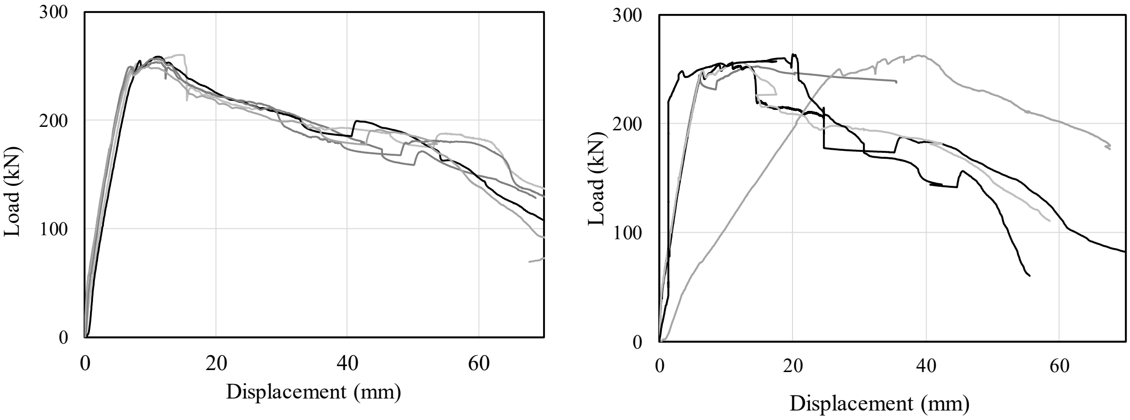


Fig. 9: Crack pattern at the failure

(upper: a/d=2.4, middle: a/d=3.2, lower: a/d=4.0)

4.4 Impact of the shear reinforcement ratio

Fig. 10 shows the load displacement relationships for RC beams with different shear reinforcement ratios. Flexural failure was exhibited in all specimens. The maximum load was approximately 250 kN for all cases, as shown in **Fig.10**. There was no significant difference in the load displacement relationship in any of the specimens when the shear reinforcement ratio was 0.36%; however, there was a large variation in the displacement behavior caused by the increase in load when the shear reinforcing bar ratio was 0.72%. **Fig. 11** shows the appearance of specimens with 0.36% of shear reinforcement ratio up to failure. There are no differences in the appearance depending on the pitch of the shear reinforcing bars by the time the failure occurred.



(a) 0.36% **(b) 0.72%**

Fig.10: Load displacement relationships for each shear reinforcement ratio

(a) At occurrence of initial bending crack(52kN) **(b) At yield of rebar (251kN)** **(c) At maximum load (259kN)**

(d) After loading test

Fig.11: Appearance of RC beam up to failure(shear reinforcement ratio 0.32%）

5. Current status of V&V in durability simulation

Durability simulations for concrete structures have long been conducted in Japan and overseas. Examples in Japan include LECCA2, which was developed by the JCI Concrete Structure Long-Term Durability Simulation Software Creation Committee15),16); and DuCOM17) developed by Maekawa et al. Both simulation codes have research cases in Japan and overseas, have been applied in practice, and they have been positioned as important tools for predicting long-term durability. These simulation codes are deterministic models, and the quantification of uncertainty in computational results is yet to be actively explored. Furthermore, in terms of validating the models, data presented in the existing literature such as the neutralization depth and distribution of chloride ion concentration are used. All these data reference the standards of academic societies, and they are values calculated on average after implementing a specified number of tests. It is rare that some statistical indices such as data distribution and variability are described in the literature. Thus, conducting V&V procedures using probabilistic models is difficult, as in the current situation in the concrete structure field described above.

In the future, a procedure in accordance with the V&V procedure will need to be followed to ensure the reliability and objectivity of future forecasts about further durability. For example, there will likely be a need to create a probabilistic model or to implement a probabilistic model for an existing model18), replace the simulation results with a simple equation, and introduce a probabilistic framework19). Furthermore, considering the experimental results required for validation, there is a need to conduct a sufficient number of tests that exceed the quantity stated in the standards from the perspective of V&V regardless of the standards of academic societies such as JIS. In addition, there is a need to publish raw data values and variations to the extent that it can be disclosed as useful information for those newly considering such topics in the future and to create a framework for sharing data with the public.

6. Conclusion

In the field of concrete engineering, evaluation and prediction by simulations are absolutely essential due to the limitation of the space and time scale. Expectations for simulations are expected to rise in the future given the rapid development of computer technologies and concrete technologies. The V&V, targeted in this technical committee, is a method for improving the quality of simulations and explaining the validation of simulation results in a rational and objective manner.

The objective of V&V is not to show the superiority or inferiority of an analysis method or to aim for a precise analysis method, but instead, it is to present reliable results within the range of the IU. Furthermore, it is important to show objective indices and to eliminate ambiguity to the highest extent possible. We hope that the activities of this technical committee will contribute to the realization of high-quality simulations in structures in concrete engineering and in the material fields in the future.

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