

# Modelling and nonlinear FE analysis of deteriorated existing concrete structures based on inspection

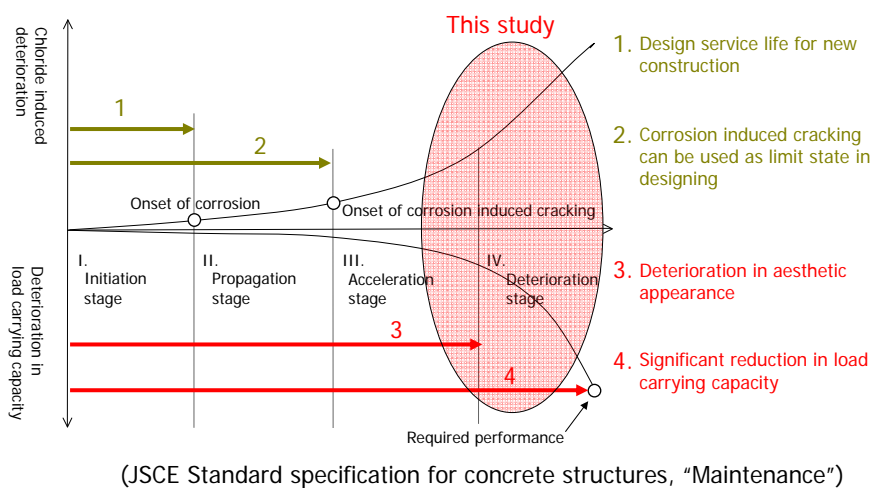
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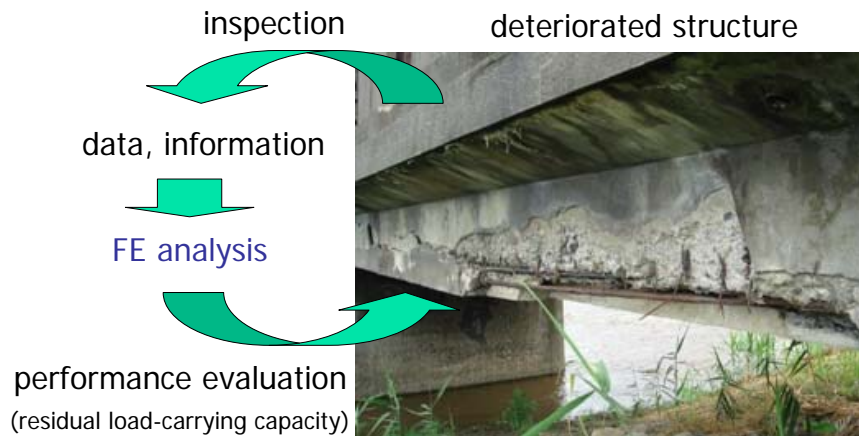
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## Deterioration processes of structures by reinforcement corrosion

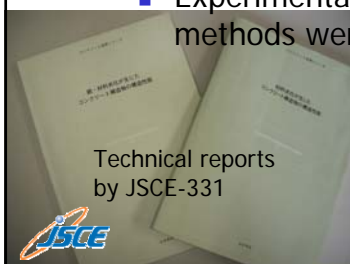


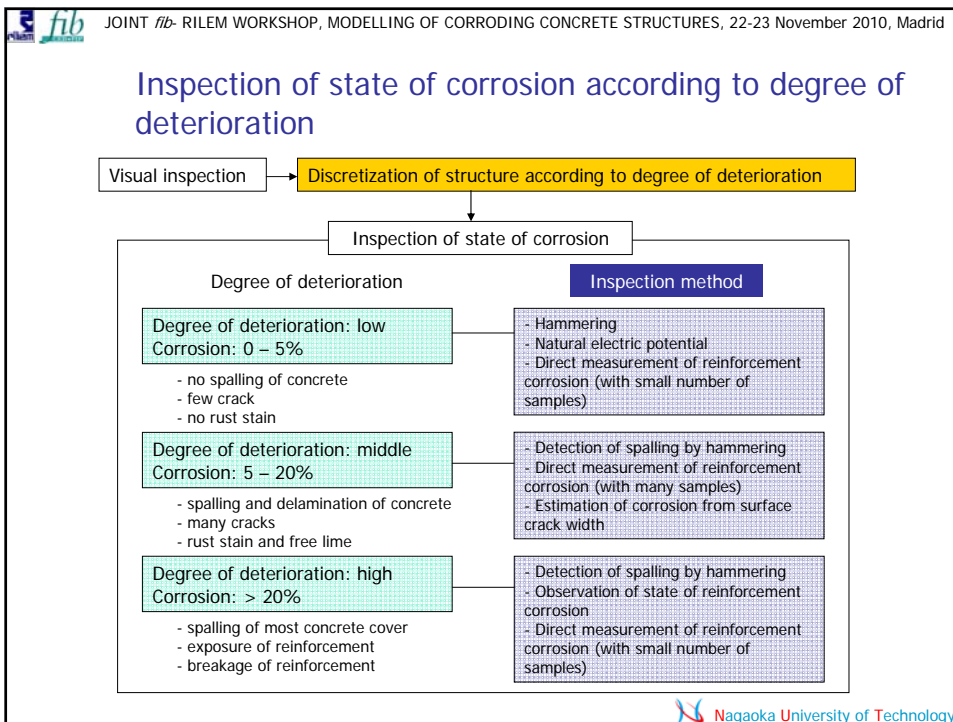
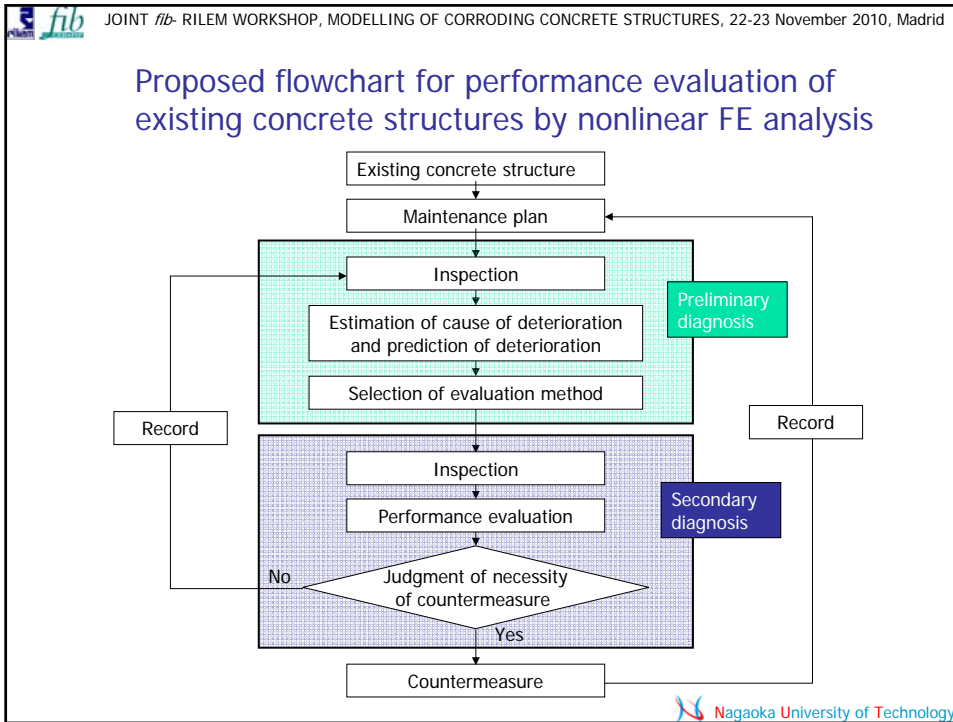
## Scope of this study



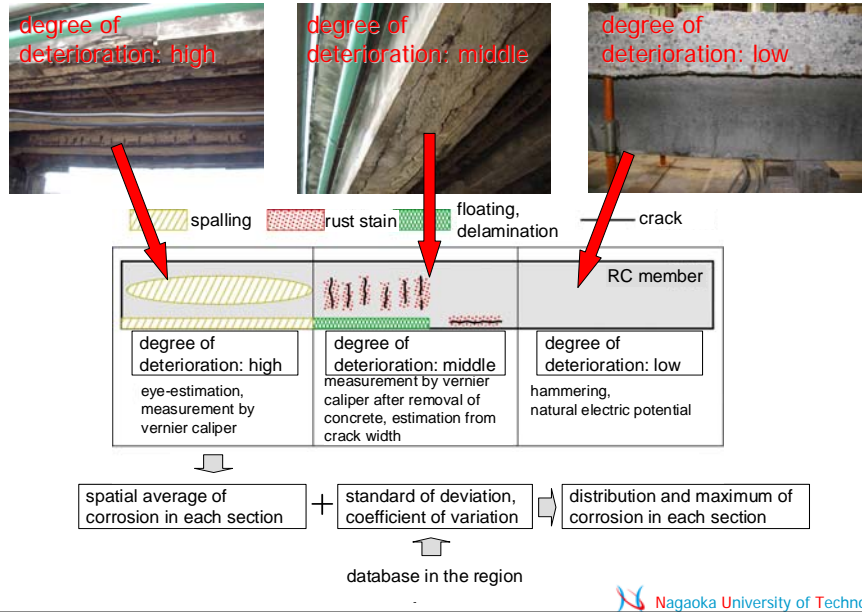
## Technical Committee JSCE-331

- Committee on Structural Performance of Deteriorated Concrete Structures (JSCE, 2004-2009)
- Research on evaluation of structural performance of concrete structures after deterioration, due to e.g. reinforcement corrosion, is focused.
- Experimental, analytical, theoretical and practical methods were systematically studied.





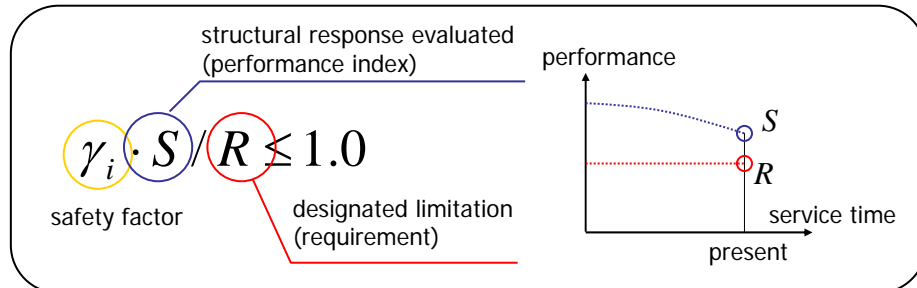
### Example procedure of determination of distribution of corrosion



### Modeling of members with reinforcement corrosion from data obtained by on-site inspection

modeling	item in modeling		method of modeling	
configuration	dimension in analysis	spatial distribution of deterioration	3-D modeling, averaging of deterioration	
	mesh for analysis	concrete	spalling, crack	delete of concrete element, reduction of bond
		reinforcement	bar arrangement, cover thickness	arrangement of reinforcement element
	boundary condition	support, connection, deflection	modeling of initial state	
material	concrete	strength, elastic modulus	adoption of measured value, consideration of spatial variation	
		stress-strain relationship in tension	consideration of bonding in terms of tension-stiffening model	
		stress-strain relationship in compression	consideration of effect of corrosion crack	
		shear stress transfer	consideration of effect of corrosion crack	
		crack	reduction of strength and elastic modulus	
	reinforcement	strength, elastic modulus	adoption of measured value or design value, consideration of strain history	
		corrosion, loss of cross sectional area	reduction of cross sectional area, consideration in stress-strain relationship	
	bond, anchorage	bonding strength, condition of anchorage	reduction of bonding stress as a function of corrosion	

## Performance Evaluation and Judgment of Countermeasure



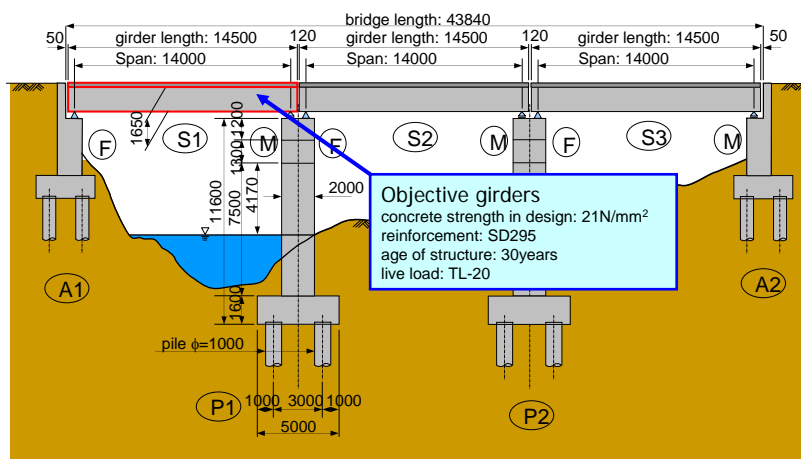
In conventional structural design: ➡

performance index  
flexural capacity, shear capacity, etc.

In performance verification using nonlinear FE analysis: ➡

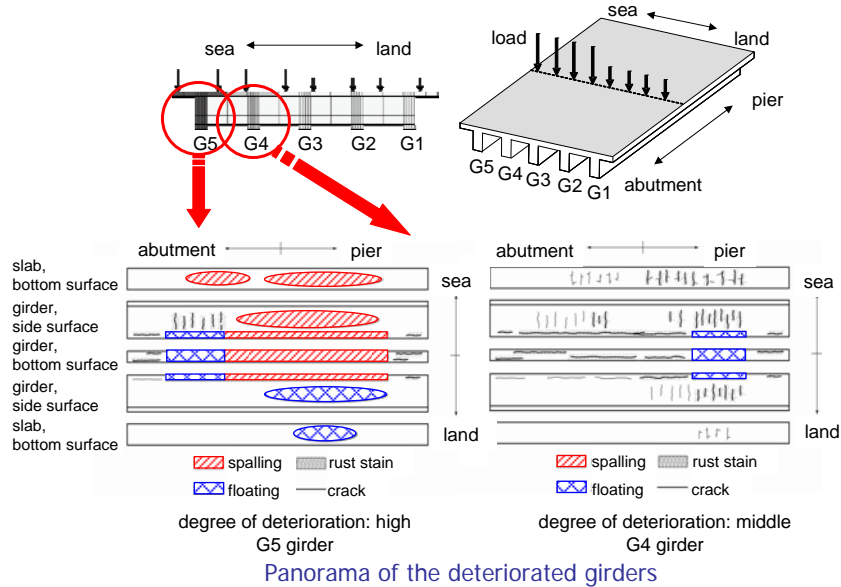
crack width, deflection, member ductility and ultimate load carrying capacity

## Integrated case study on evaluation of residual structural performance of existing concrete structure by nonlinear FEA



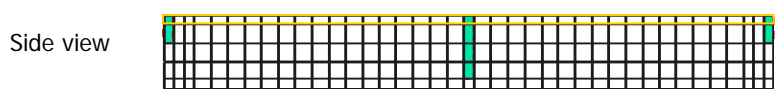
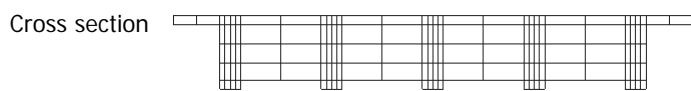
RC simple girder bridge with three clear spans and five main girders near the coast

## Objective girders and their deterioration state

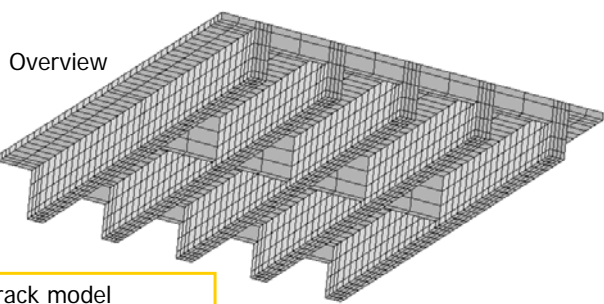


## Finite Element Mesh

Original 3D Nonlinear FE program was used.



- 24603 nodes
- 4440 elements
- Element size: 400mm (in longitudinal direction)



- Smearing crack model
- Smearing reinforcement model

## Analytical cases

		Position of deteriorated girders G5 G4 G3 G2 G1					Position of deteriorated girders G5 G4 G3 G2 G1				
Main	CASE1										
	CASE3										
Additional	CASE4										
	CASE5										

sound girder

moderate deterioration

high deterioration

## Modelling of deterioration

In FE mesh and material characteristics,

Loss of cross sectional area of reinforcement due to corrosion

→ Considered in terms of reinforcement ratio

Loss of cross sectional area of concrete cover due to spalling

→ not considered

Reduction of material strength and elastic modulus

→ not considered

In constitutive models,

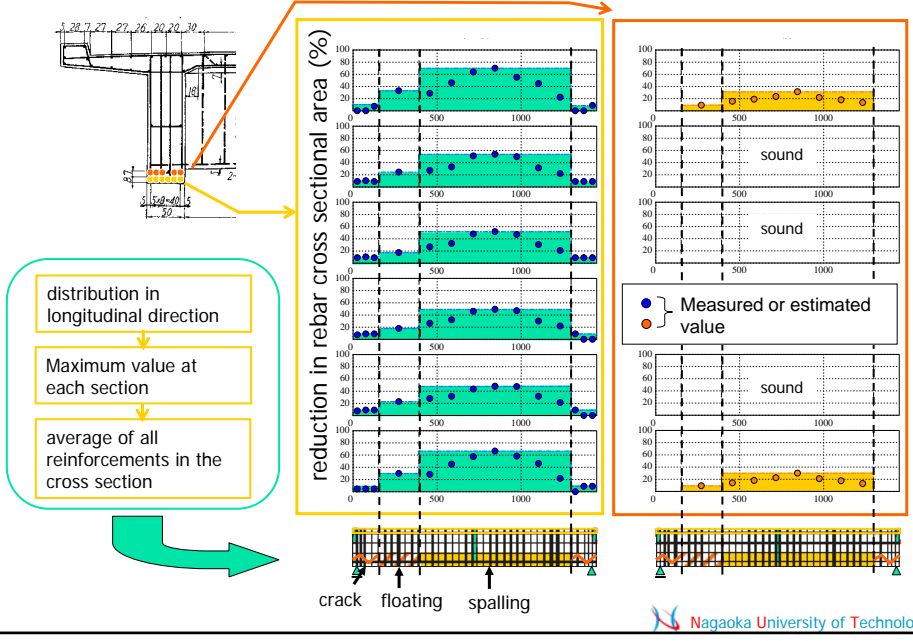
Corrosion crack

→ not considered

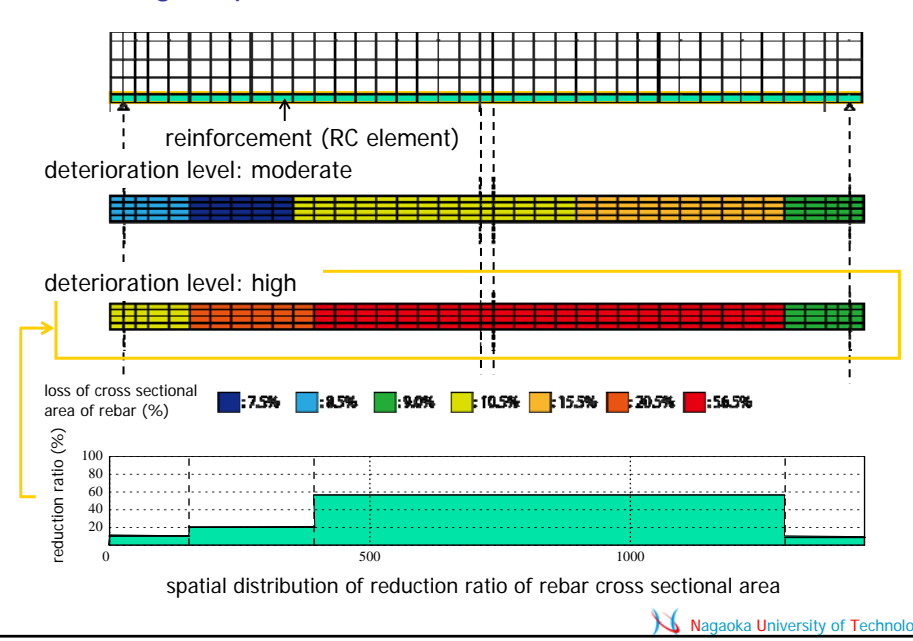
Deterioration in bonding

→ Considered in terms of stress-strain relationship of concrete (tension stiffening model)

### Modelling of spatial distribution of corrosion



### Modelling of spatial distribution of corrosion (cont.)



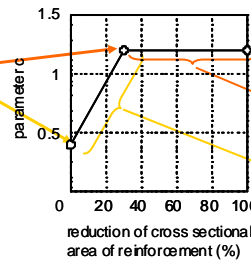
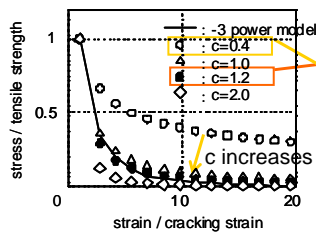


## Consideration of deterioration in terms of constitutive model

Deterioration in bonding

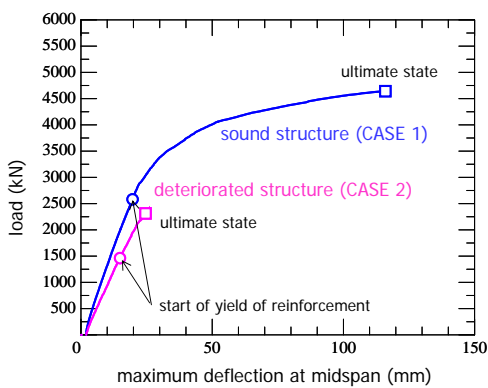
Considered in terms of stress-strain relationship of concrete (tension stiffening model)

$$\frac{\sigma}{f_t} = \left( \frac{\varepsilon_t}{\varepsilon} \right)^c$$

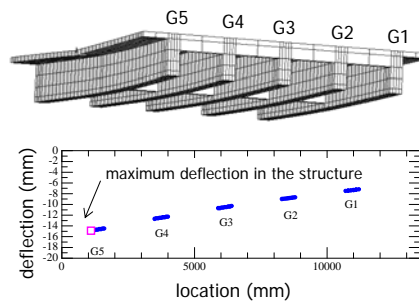


tension stiffening model considering effect of reinforcement corrosion

## Analytical results: load-deflection curve of structure



load-deflection curve of deteriorated structure being compared with sound one



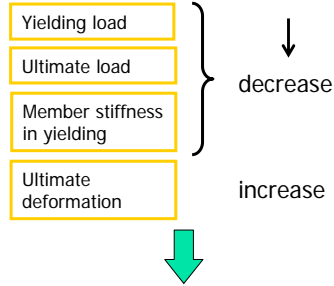
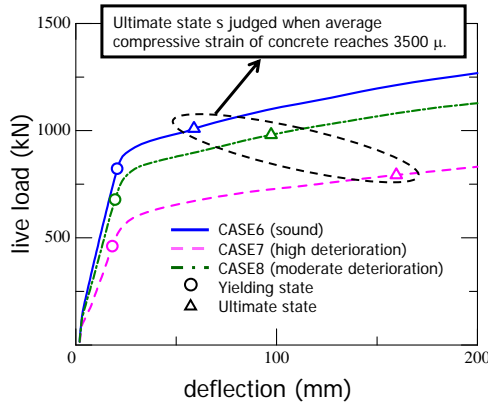
deformation of the deteriorated structure at the yielding load

Ultimate state is judged when average compressive strain of concrete reaches 3500  $\mu$ .

## Analytical results: individual girders

Analytical Case	Normalized capacity	
	Yielding load	Ultimate load
CASE6 (sound)	1.00	1.00
CASE7 (high deterioration)	0.56	0.79
CASE8 (moderate deterioration)	0.82	0.97

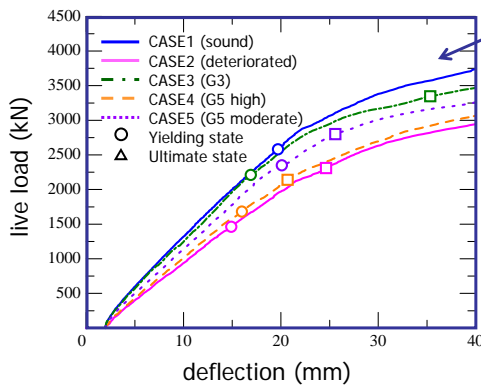
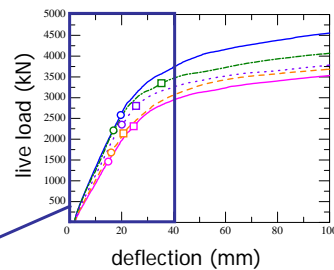
With increasing of deterioration (reduction of reinforcement)



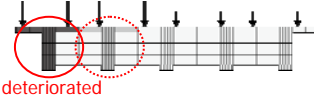
General tendencies in response of corroded RC beam

## Analytical results: numerical experiment on the effect of location of deteriorated member on overall behavior of the structure

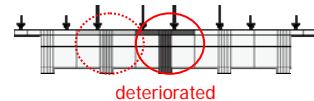
Analytical Case	Normalized capacity	
	Yielding load	Ultimate load
CASE1 (sound)	1.00	1.00
CASE2 (G5 is deteriorated)	0.77	0.66
CASE3 (G3 is deteriorated)	0.92	0.81
CASE4 (G5 high)	0.81	0.64
CASE5 (G5 moderate)	0.95	0.73

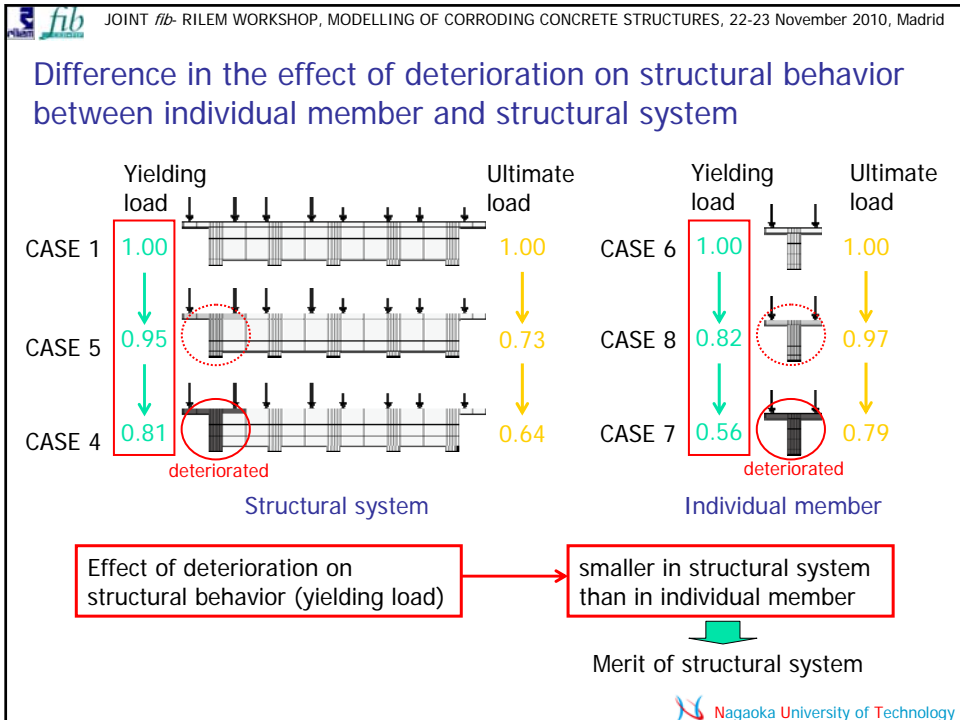


Structural performance of CASE2 is the lowest.



Structural performance of CASE3 in which G3 is deteriorated is closest to sound case.





JOINT fib- RILEM WORKSHOP, MODELLING OF CORRODING CONCRETE STRUCTURES, 22-23 November 2010, Madrid

## Conclusions

- General procedure of assessment of residual structural performance of deteriorated existing concrete structures by nonlinear FE analysis and integrated case study were introduced.
- In detailed inspection of existing structure in prior to nonlinear FE analysis, it is necessary to collect information about deterioration in the structure enough to represent them in the analysis effectively.
- In nonlinear FE analysis of deteriorated concrete structures, it is essential to adequately consider degree and spatial distribution of deterioration such as corrosion of reinforcement and spalling of concrete.
- It is advantageous to analyze whole structural system instead of part of the structure when performance of deteriorated structure is assessed by nonlinear FE analysis.

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