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Additional Information

# A numerical study into the evolution of loads on shores and slabs during construction of multistorey buildings. Comparison of partial striking with other techniques

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## Abstract

This paper contains a summary and evaluation of an experimental research project carried out at the ICITECH laboratories, Valencia, Spain. The project consisted of the construction of a full-scale building that included a process of shoring, clearing and striking (SCS). The experimental model was used as the basis for the development of a FE model, including an evolving calculation, with the objective of simulating the construction process used, as well as studying the evolution of concrete properties during the test. The FE model was verified with the results obtained from the experimental model. Two further FE models were then developed from the original model and were used to simulate the construction of the same building using two different construction processes: one involving shoring and striking (SS) and the other shoring, re-shoring and striking (SRS). Finally, the SCS was compared to the SS and SRS processes, respectively, and an analysis was made of the advantages and disadvantages of each one. The paper breaks new ground in that for the first time ever a comparative study is made of the three most frequently used shoring techniques.

*Keywords:* shoring; finite element modelling; formwork; multistorey buildings; construction; partial striking.

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## 1. Introduction

During the construction of multistorey buildings the shoring of the topmost slabs has to be supported on the recently cast lower slabs, which are thus subjected to considerable loads during the construction process and often the cause of a great number of building collapses during shoring-striking [1-3]. International standards [4-6] lay down highly conservative criteria to define striking times, which are often far removed from customary building practices [7]. The correct calculation of shoring and striking times requires knowledge of how loads are transmitted between slabs and shoring during the construction of multistorey buildings.

Various theoretical and experimental studies have been carried out on the question of how loads are transmitted between shoring and slab. In 1963, Grundy and Kabaila [8] proposed a simplified method, which is still being used, to determine the loads on these elements. This method is easy to apply and in most cases errs on the side of safety.

Further studies by other authors such as Liu et al. [9], Stivaros and Halvorsen [10], Mosallam and Chen [11], Duan and Chen [12], Moragues et al. [13], Fang et al. [14], Beeby [15], Díaz [16] and Alvarado et al. [7] all agree that Grundy and Kabaila's simplified method [8] overestimates the loads on shores and slabs. This is mainly due to the fact that these authors consider shores to be infinitely stiff.

Most studies on load transmission between slabs and shores have used the processes of (i) shoring and striking (SS) and (ii) shoring, re-shoring and striking (SRS). Moragues et al. [13] and Alvarado et al. [7] are the only authors to date to have studied shoring, clearing (partial striking) and striking (SCS).

SCS involves an intermediate operation known as clearing, which consists of removing the formwork and over half of the slab-supporting shores a few days after pouring (See Fig. 1). This operation considerably reduces the materials required for formwork and shoring [7], has a beneficial effect on building costs and improves construction efficiency.

In order to analyse the effect of SCS on load transmission between slabs and shoring, an experimental study was carried out in the laboratories of the Institute of Concrete Science and Technology (ICITECH in the Spanish abbreviation). The study consisted of constructing a three-storey building with reinforced concrete slabs 0.25 m thick. The results obtained from this study were previously analysed by Alvarado et al. [7] and Alvarado [17].

This paper describes the finite element modelling (FEM) of the building studied by Alvarado et al. [7]. The FE model takes into account the variations in concrete properties with time and each of the building phases, making it possible to analyse the transmission of loads between slabs and shores in the SCS process.

One of the most important hypotheses in the FE model is based on simulating shores as elastic elements with finite stiffness, an aspect not considered by Grundy and Kabaila [8]). This hypothesis is essential for simulating the loss of stiffness in the shoring caused by removing half of the shores in the clearing process.

The proposed FE model was verified from the experimental results by a comparison with periodical measurements taken during each of the building stages.

After verifying the FE model of the purpose-built structure erected on the ICITECH premises, the same method was employed to study other building techniques not considered in the experimental study. These included two new models in which the same building was analysed by FEM during respective SS and SRS processes. With the results obtained from the three FE models (SCS, SS and SRS), SCS was compared with the other two techniques to establish the pros and cons of each process.

The study described in this paper includes for the first time a comparison of the three most frequently used shoring methods. Both quantitative and qualitative results are given.

## **2. Summary of the experimental study**

### *2.1. General*

The experimental building comprised three storeys of 0.25 m thick RC floor slabs, with a 6.00 m clear span between columns. The slabs were supported on rectangular section columns, cantilevered 1.80m. The height between floors was 2.75 m. Due to soil conditions, the foundation of the building was a 0.40 m thick reinforced concrete slab with a ground plan of 10.20 m by 9.40 m. Fig. 2 shows a view of the experimental model.

The proposed construction process was based on maintaining the shoring on two consecutive storeys. A load similar to the weight of a slab was applied to slab 3 to simulate three consecutively shored storeys. The construction process is illustrated in Figs. 3, 4 and 5.

A total of 80 shores were instrumented. Three strain gauges were placed on each one set at an angle of 120° and a height of 1.25 m. from the base of the shore. The average deformation value of the three gauges was used to establish the load that each of the shores would be subjected to during the building of the structure.

40 data acquisition modules were used to take readings from the strain gauges. The data compiled by the acquisition system were processed in 2 computers equipped with software developed at ICITECH.

A complete description of the experimental study can be found in Alvarado et al [7] and Alvarado [17].

## *2.2. Readings obtained*

Strain gauges were used to take readings of the loads in shores and slabs during the different building phases. To facilitate analysis, the load evolution study was divided into two parts:

- a) Continuous recordings: These were considered to be the basic experimental readings. They measured deformations and loads in all shores from their being put into place and before casting until their removal in the clearing phase. The data thus obtained recorded load variations due to building operations and also those existing between operations due to construction loads or temperature variations.
- b) Periodical recordings: In order to distinguish the effects caused by building operations (casting, clearing and striking) from those due to construction loads or variations in atmospheric conditions (humidity and temperature) between building phases, readings were taken of the loads at intervals during building operations. The increased loads caused by casting, clearing and striking were thus analysed individually in shores and slabs. The recording of these increased (momentary) loads during the construction of the experimental building provided information on how the loads generated during casting, clearing and striking were transmitted between slabs and shores, without interference from the distortions caused by variations in the readings between building phases.

The results obtained from the continuous readings are analysed in Alvarado et al. [7]. The results obtained from the periodical readings, later used in the FEM study, are summarised below. A complete analysis of the periodical readings is available in Alvarado [17].

### 2.3 Analysis of periodical readings

Table 1 gives the data obtained from periodical readings during each construction phase. An analysis of these results shows that:

- a) When each slab was being cast the total load was transmitted to the shores. Maximum error between mean load recorded on the shores ( $Q_{med}$ ) and the theoretical value was 3% and occurred during the casting of slab 1. This verifies the accuracy of the readings obtained during the test.
- b) After clearing, the three slabs supported a high proportion of the load in the following way:
  - After clearing slab 1, where shores were resting on the foundation slab, the slab supported a weight equal to 46% of its self-weight and the shores supported 54%.
  - After clearing slab 2, where shores were resting on slab 1, with slab 1 resting on the foundation slab, the slab supported a load equal to 48% of its self-weight and the shores supported 52%.
  - After clearing slab 3, where shores were resting on slab 2, with slab 2 resting on slab 1, the slab supported 45% of its self-weight and the shores supported 55%.
- c) When a load was applied to a cleared slab or when slabs resting on lower cleared slabs were cast, the load was distributed as follows:
  - After casting slab 2, 74% of the load transmitted by the shores below this slab was assumed by slab 1. The remaining 26% was assumed by the shores supporting slab 1 and was transmitted to the foundation slab.
  - After casting slab 3, the load was shared between slabs 1 and 2. Of this, 26% was supported by slab 1 and the load assumed by slab 2 was around 72% of the self-weight of slab 3.
  - On applying an evenly distributed load to slab 3, 11% of this load was transmitted to slab 1, 11% to slab 2 and 78% to slab 3.

From the above figures, it can be concluded that a cleared slab supported on average 75% of a new load applied to it.

- d) After striking, the load that had been supported by the shores was transmitted to higher slabs through the shores. After striking slabs 1 and 2, the load was transmitted as follows:
- After removing the shores from slab 1, 69% of the load they had supported was assumed by slab 1 and the remaining 31% by slab 2.
  - After removing the shores from slab 2, 80% of the load they had supported was transferred to slab 2 and the remaining 20% to slab 3.

### **3. Finite element model of an SCS process**

This section describes the FE model of the experimental test described in Section 2. For this model ANSYS 11.0 commercial software [18] was used. The geometric and mechanical characteristics of all the elements that formed part of the construction of the building were considered, as was the construction process by means of an evolving calculation, to enable the simulation of load transmission between slabs and shores within an SCS process.

#### *3.1. Hypotheses considered*

The geometrical characteristics of the elements in the experimental test are as described in Section 2. The building process was modelled in the phases shown in Figs. 3, 4 and 5. The hypotheses adopted to create the FE model were as follows:

- The reinforced concrete slabs were assumed to have linear elastic behaviour and variations in their stiffness during the test were considered.
- Columns were modelled with linear elastic behaviour and variations in their stiffness during the test were considered.
- The steel shores were considered as elastic elements with finite stiffness, supported at the ends. Their geometric characteristics are given in Table 2.

- Formwork boards were considered with linear elastic behaviour and finite stiffness. Boards were made of wood 27 mm thick with a 19 GPa elastic modulus.
- Straining pieces were simulated with linear elastic behaviour and finite stiffness. They were made of steel with a cross section of 406 mm<sup>2</sup> and elastic modulus of 210 GPa.
- The foundation was considered to be infinitely stiff. This hypothesis was adopted after establishing that the shores of the first level of slabs were resting directly on the foundation slab.
- Creep and shrinkage effects in the concrete and temperature changes in the elements were not taken into account. This hypothesis was considered valid since the building phases in which load increases were analysed were of short duration.

### *3.2. Finite elements and meshing*

Concrete slabs and wooden formwork boards were modelled by two-dimensional SHELL63 elements [19]. The elements were formed by 4 nodes with 6 degrees of freedom per node (translations and rotations in X, Y and Z).

Steel shores were modelled by 2-node one-dimensional LINK10 elements [19] with 3 degrees of freedom per node (translations in X, y and Z). Options included considering that they were only subjected to compression forces, the ideal for modelling shores.

To model concrete columns and steel straining pieces BEAM44 elements were used [19]. The BEAM 44 element has two nodes (I,J) and a third optional node (K) that defines element orientation. This element has 6 degrees of freedom per node (translations and rotations in X, Y and Z) and allows nodes to be displaced from the section axis (ideal for transferring nodes to each column growth point).

Figure 6 shows the SHELL63, LINK10 and BEAM44 elements.

The size of the shore mesh is influenced by shore dimensions and the distribution of shoring and formwork components. To obtain a suitable degree of approximation, the FE mesh size used for slabs and formwork was 0.20x0.20 m<sup>2</sup>. The mesh size used for concrete columns was de 0.58 m and for straining pieces was 0.20 m.



### 3.3. Simulation of the building process

To simulate the building process, the FE model was considered as an evolving structure, i.e. the shoring conditions (shores, straining pieces and formwork) and the mechanical characteristics of the concrete varied through time.

ANSYS 11.0 [18] allows an evolving calculation to be performed by means of different load steps. A load step consists of calculating the structure with the material geometry and properties corresponding to each of the building phases considered. After solving the first load step, the second load step is then based on the load and deformation values obtained from the first. An evolving calculation is thus performed with a load step for each building phase.

To perform this calculation, ANSYS 11.0 [18] has Birth and Death options and the MPCHG command. The Birth and Death option is based on activating and de-activating the structural elements to be calculated. To de-activate structural elements within a load step the EKILL command is used. This reduces the stiffness value of the element under consideration, multiplying it by a factor of 1.0E-6 (default value assigned by the program, but can be changed). When an element is de-activated, its associated loads are eliminated. To activate an element, the EALIVE command is used. This assigns the appropriate stiffness to the selected elements and recovers the load values associated with them.

The evolution of the concrete elastic modulus in time is performed by the MPCHG command, which enables changing the type of material assigned to the selected elements. Materials can thus be created in the FE model with the appropriate elastic modulus for the age of the concrete for each slab in each construction phase. The elastic modulus of the slab elements can later be changed in each load step according to the age of the concrete in the phase under consideration. Concrete slabs' elastic modulus is obtained from laboratory tests on normalized specimens. The maturity method is used for determining the evolution of the concrete slabs' elastic modulus. This is described in detail in Alvarado [17] and is similar to that used by Waller et al. [20] and Adam et al. [21].

Simulation of the evolving process with ANSYS 11.0 [18] is carried out in three stages:

- a) Definition of type of finite elements, material characteristics, geometry and mesh of the structure and the loads applied. The complete FE model is defined in this stage, defining the three slabs, columns and formwork system. Fig. 2(b) shows the model thus obtained.

b) The 9 load steps corresponding to the 9 building phases are then solved. The Birth and Death options are used in this phase and the MPCHG command available in ANSYS 11.0 [18].

c) The results of each of the load steps considered are extracted for subsequent analysis.

The load steps followed in the FE model correspond to the 9 building stages shown in Figs. 3, 4 and

5. Details of the load steps are as follows:

1) Casting of Level 1 (0 days). The upper level slab elements are de-activated, including shoring (shores, straining pieces and formwork), leaving active only level 1 elements with shoring.

2) Clearing of level 1 (3 days). Formwork boarding, intermediate straining pieces and the corresponding shores are de-activated.

3) Casting of level 2 (7 days). Level 2 elements are activated, including columns, formwork boards, straining pieces and shores.

4) Clearing of level 2 (13 days). Formwork boards, intermediate straining pieces and the corresponding shores are de-activated from level 2.

5) Striking of level 1 (14 days). Shores and straining pieces under level 1 are de-activated, leaving only shores and straining pieces under level 2.

6) Casting of Level 3 (17 days). The level 3 slab elements are activated, including columns and shoring (formwork boards, straining pieces and shores).

7) Clearing of level 3 (20 days). Formwork boards, shores and intermediate straining pieces are de-activated to simulate clearing of level 3.

8) Loading level 3 (24 days). A uniform load is applied to level 3 elements.

9) Striking of level 2 (25 days). Shores and straining pieces under level 2 are de-activated

In each of the above load steps, concrete elasticity modulus is varied in accordance with its time evolution.

### *3.4. Verification of the FE model*

In order to verify the FE model, a comparison between the experimental results and FE results was carried out. Table 3 gives a comparison of mean load values (periodical readings) in shores obtained from the experimental model ( $Q_{med,exp}$ ) and those obtained from the FE model ( $Q_{med,FEM}$ ). As can be seen, there

is a good fit between both results. The mean of the  $Q_{\text{med,exp}}/Q_{\text{med,FEM}}$  ratio of all construction phases is 0.96 with a standard deviation of 0.15.

The most significant differences between experimental and numerical results are given in phases 3 and 4. As Alvarado [17] points out, these differences are due to an error made when removing the formwork from level 1, which redistributed the loads between the slab and shores. No allowance was made for this error in the numerical model.

After verifying the model, the next step was to perform FE simulations to analyse the proposed SS and SRS processes.

#### **4. Finite element model of a SS process**

##### *4.1. Construction phases and load steps*

Using as a base the FE model described in Section 3, a new model was created to simulate the construction of the building itself while using the SS process. The method used in the modelling was identical to that described above, adopting the building phases or load steps shown in Fig. 7. The main characteristics of each of these load steps were as follows:

- 1) Casting of level 1 (0 days). Upper level elements were de-activated, including the shoring system (shores, straining pieces and formwork boards) leaving active only level 1 elements with its shoring.
- 2) Casting of level 2 (7 days). Level 2 slab elements were activated, including columns, formwork boards, straining pieces and shores.
- 3) Striking of level 1 (14 days). Shores, straining pieces and formwork boards of level 1 are de-activated.
- 4) Casting of Level 3 (17 days). The level 3 slab elements are activated, including columns and shoring (formwork boards, straining pieces and shores).
- 5) Loading level 2 (24 days). A uniform load is applied to level 3 elements, simulating the weight of another slab with the same characteristics.
- 6) Striking of level 3 (25 days). Shores under level 2 are de-activated.

As in Section 3, in each of the above load steps the concrete elasticity modulus is varied in accordance with its time evolution.

#### *4.2. Equivalence of SCS and SS load steps*

The number of days needed to carry out each of the above described operations coincides for the phases common to the SCS and SS processes. The equivalence between the SCS and SS process load steps is as follows:

- Load step 1 (Casting of level 1) of the SS process with SCS load step 1 (Casting of level 1).
- Load step 2 (casting level 2) of the SS process with SCS load step 3 (casting level 2).
- Load step 3 (striking level 1) of the SS process with SCS load step 5 (striking level 1).
- Load step 4 (casting level 3) of the SS process with SCS load step 6 (casting level 3).
- Load step 5 (loading level 3) of the SS process with SCS load step 8 (loading level 3).
- Load step 6 (striking level 2) of the SS process with SCS load step 9 (striking level 2).

#### *4.3. Comparing the SCS and SS processes*

Figures 9, 10 and 11 show the mean load coefficients for the shores at each level obtained from the ratio of mean shore load per surface unit/self-weight of the slab, given by the FE simulations of the SCS and SS processes.

From the comparison of the two processes, the following conclusions can be drawn:

- When clearing is carried out in SCS, the slabs assume a considerable part of the load (40% for level 1, 49% for level 2 and 51% for level 3). This reduces the average load supported by the shores (although individual shores may have to support a higher load from a larger tributary area).
- Maximum mean load on shores for both processes occurs in level 1 during casting of the level 2 slab.
- The load level on shores is higher in the SCS than SS process. However, the number of shores after clearing in SCS is around 50% of the number of shores in an SS process, so that the

tributary area acting on each shore is greater in SCS. Consequently, the individual load assumed by individual shores may be higher with this system.

- The SCS process needs 77 m<sup>2</sup> of formwork boarding, 140 m of steel straining pieces and 160 shores. The SS process needs 144 m<sup>2</sup> of formwork boarding, 209 m of steel straining pieces and 240 shores. The SCS process therefore employs 53% fewer formwork boards and 66% fewer shores and straining pieces than the SS process.

## **5. Finite element model of a SRS process**

### *5.1. Construction phases and load steps*

Following the procedure described in Section 4.1, another simulation of the same building was carried out using an SRS process. Figure 8 shows the construction phases or load steps followed in this new FE model. The main characteristics of each of the load steps considered is as follows:

- 1) Load step 1 (Casting of level 1) (0 days). Elements of the upper levels were de-activated, including shoring (shores, straining pieces and formwork boards) leaving active only level elements with their shoring system.
- 2) Load step 2 (Re-shoring of level 1) (5 days). This load step was divided into two parts. In the first, the shores, straining pieces and formwork boards that supported level 1 were de-activated, so that this slab now supported its self-weight. In the second part, the shores supporting level 1 were re-activated.
- 3) Load step 3 (Casting of level 2) (7 days). The level 2 set of elements were activated, including columns, formwork boards, straining pieces and shores.
- 4) Load step 4 (Re-shoring of level 2) (13 days). Re-shoring of level 2 was simulated in two stages. In the first, shores, straining pieces and formwork under level 2 were de-activated. In the second, the shores supporting level 2 were re-activated. At the end of this load step, these shores therefore were not subjected to any load value.
- 5) Load step 5 (Striking of level 1) (14 days). Shores under level 1 were de-activated. Shores under level 2 remained active.

- 6) Load step 6 (Casting of level 3) (17 days). Activation of the temporary structure (shores, straining pieces and formwork boards), columns and elements forming level 3.
- 7) Load step 7 (Re-shoring of level 3) (22 days). In the first part, shores, straining pieces and formwork boards of level 3 are de-activated (so that level 3 now supported its self-weight). Shores under level 3 were then activated.
- 8) Load step 8 (Loading level 3) (24 days). A uniform load was applied to the elements of level 3, simulating the weight of another slab with the same characteristics.
- 9) Load step 9 (Striking of level 2) (25 days). The final load step consisted of de-activating the shores under level 2.

As in Section 3, in each of the above load steps the concrete elasticity modulus was varied in accordance with its evolution during the test.

## *5.2. Equivalence of SCS and SRS load steps*

The number of days required to carry out each of the operations defined above coincided for the phases common to the SCS and SRS processes. The time needed for re-shoring was established considering an ambient temperature of 10°C and that the slab was able to support its self-weight plus construction loads at an age of 5 days. The basis for these considerations is described in Alvarado et al. [17].

The equivalence between the SCS and SRS load steps is as follows:

- Load step 1 (Casting slab 1) of the SRS process with load step 1 (Casting slab 1) of the SCS process.
- Load step 2 (Re-shoring level 1) of the SRS process with load step 2 (Clearing level 1) of the SCS process.
- Load step 3 (Casting level 2) of the SRS process with load step 3 (casting level 2) of the SCS process.
- Load step 4 (Re-shoring level 2) of the SRS process with load step 4 (Clearing level 2) of the SCS process.

- Load step 5 (Striking level 1) of the SRS process with load step 5 (Striking level 1) of the SCS process.
- Load step 6 (Casting level 3) of the SRS process with load step 6 (Casting level 3) of the SCS process.
- Load step 7 (Re-shoring level 3) of the SRS process with load step 7 (Clearing level 3) of the SCS process.
- Load step 8 (Loading level 3) of the SRS process with load step 8 (Loading level 3) of the SCS process.
- Load step 9 (Striking level 2) of the SRS process with load step 9 (Striking level 2) of the SCS process.

### 5.3. Comparing the SCS and SRS processes

Figures 12, 13 and 14 show mean load coefficients for shores placed under each of the slabs obtained from the ratio of mean shore load per surface unit/slab self-weight by the FE models that simulated the SCS and SRS processes.

From the comparison of the SCS and SRS processes it can be concluded that:

- Mean shore loads are higher in the SCS than the SRS process. However, the number of shores used in SCS is about 50% lower than those required for SRS. Individual shore loads will therefore be higher in the SCS process.
- The shores in SRS never assume a load greater than the self-weight of each of the slabs. In SCS, the maximum load assumed is of the order of 118% of the self-weight of the slab (in level 1 after casting level 2).
- For the SCS process, 77 m<sup>2</sup> of formwork boards, 140 m of steel straining pieces and 160 shores are required. For SRS, 77 m<sup>2</sup> of formwork boarding, 105 m of steel straining pieces and 240 shores are necessary. The SCS process therefore requires 67% of the shores and 133% of the straining pieces needed for the SRS process.

## 5. Conclusions

This paper describes the FE modelling of a building constructed in the ICITECH laboratories, previously analysed by Alvarado et al. [7]. The developed FE model considered the construction process followed in the experimental model, as well as the evolution of the concrete properties during the test. It was thus possible to simulate load transmission between shores and concrete using an SCS process.

The FE model was verified by the experimental results and it was concluded that the method adopted in the models is suitable for use in actual buildings.

With the same FE model, two new models were generated to simulate SS and SRS processes in the same experimental building in order to compare SCS with the SS and SRS processes, respectively.

The principal novelty of the paper lies in the fact that the three most commonly used shoring techniques have been compared for the first time, thus highlighting the advantages and disadvantages of each one.

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Fig. 8. Construction phases and load steps of the SRS process

Fig. 9. Comparison of SCS and SS processes (Load coefficients in shores supporting level 1)

Fig. 10. Comparison of SCS and SS processes (Load coefficients in shores supporting level 2)

Fig. 11. Comparison of SCS and SS processes (Load coefficients in shores supporting level 3)

Fig. 12. Comparison of SCS and SRS processes (Load coefficients in shores supporting level 1)

Fig. 13. Comparison of SCS and SRS processes (Load coefficients in shores supporting level 2)

Fig. 14. Comparison of SCS and SS processes (Load coefficients in shores supporting level 3)

Table 1. Loads on shores at each construction stage (periodical readings).

Table 2. Geometrical and mechanical characteristics of the shores

Table 3. Comparison between experimental and FEM results

**Table 1**  
Loads on shores at each construction stage (periodical readings)

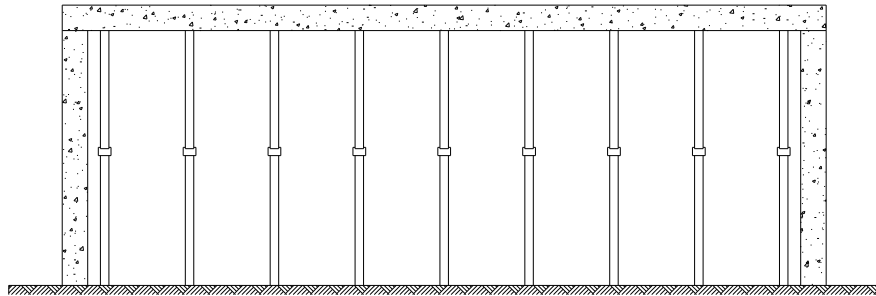
Step	Stage of construction	Level	$Q_{med}$ (KN/m <sup>2</sup> )	$P_{max}$ (KN)
1	Casting Level 1	1	5.64	7.71
2	Clearing Level 1	1	3.07	8.43
3	Casting Level 2	2	5.60	8.63
		1	4.48	14.57
4	Clearing Level 2	2	2.91	8.08
		1	3.86	11.30
5	Striking Level 1	2	1.57	4.88
6	Casting Level 3	3	5.50	8.84
		2	3.07	8.23
7	Clearing Level 3	3	3.12	11.27
		2	2.78	7.28
8	Load in Level 3	3	4.33	17.40
		2	3.38	7.28
9	Striking Level 2	3	3.67	13.86

**Table 2**  
Geometrical and mechanical characteristics of the shores

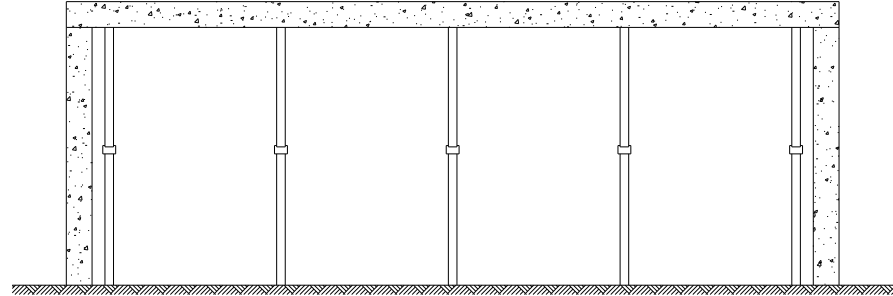
Length (m)	Diameter (m)	Thickness (m)	Elasticity modulus (GPa)
2.88	0.048	0.002	210

**Table 3**  
Comparison between experimental and FEM results

Step	Stage of construction	Level	$Q_{med,exp}$ (KN/m <sup>2</sup> )	$Q_{med,FEM}$ (KN/m <sup>2</sup> )	$Q_{med,exp}/Q_{med,FEM}$
1	Casting Level 1	1	5.46	5.52	0.99
2	Clearing Level 1	1	3.07	3.41	0.90
3	Casting Level 2	2	5.60	5.80	0.97
		1	4.48	6.60	0.68
4	Clearing Level 2	2	2.91	2.90	1.00
		1	3.86	5.33	0.72
5	Striking Level 1	2	1.57	1.39	1.13
6	Casting Level 3	3	5.50	5.80	0.95
		2	3.07	3.04	1.01
7	Clearing Level 3	3	3.12	2.77	1.13
		2	2.78	2.19	1.27
8	Load in Level 3	3	4.33	5.37	0.81
		2	3.38	3.36	1.01
9	Striking Level 2	3	3.67	4.23	0.87
-	Mean	-	-	-	0.96
-	Standard deviation	-	-	-	0.15



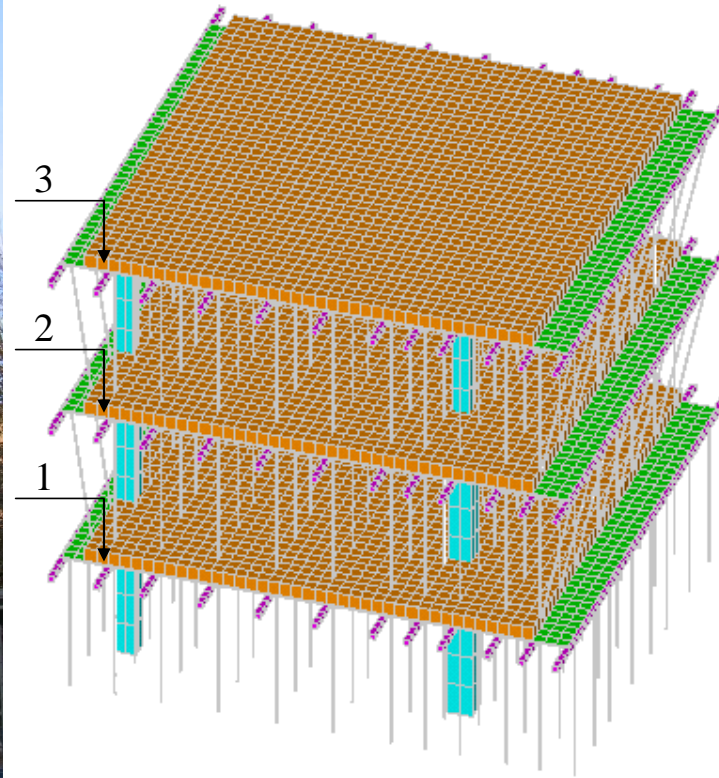
Casting slab



Clearing slab



Fig. 1. Clearing

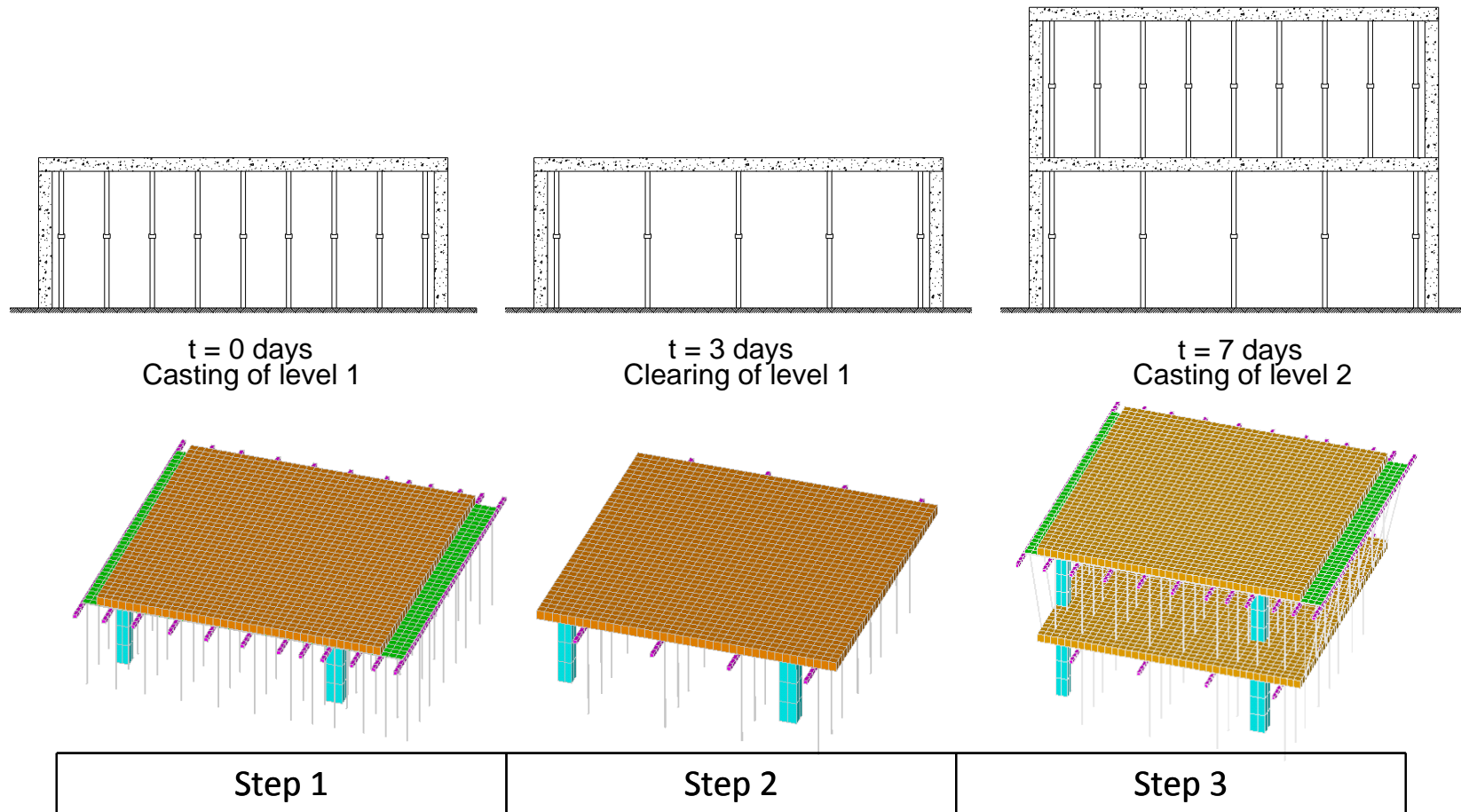


Experimental model

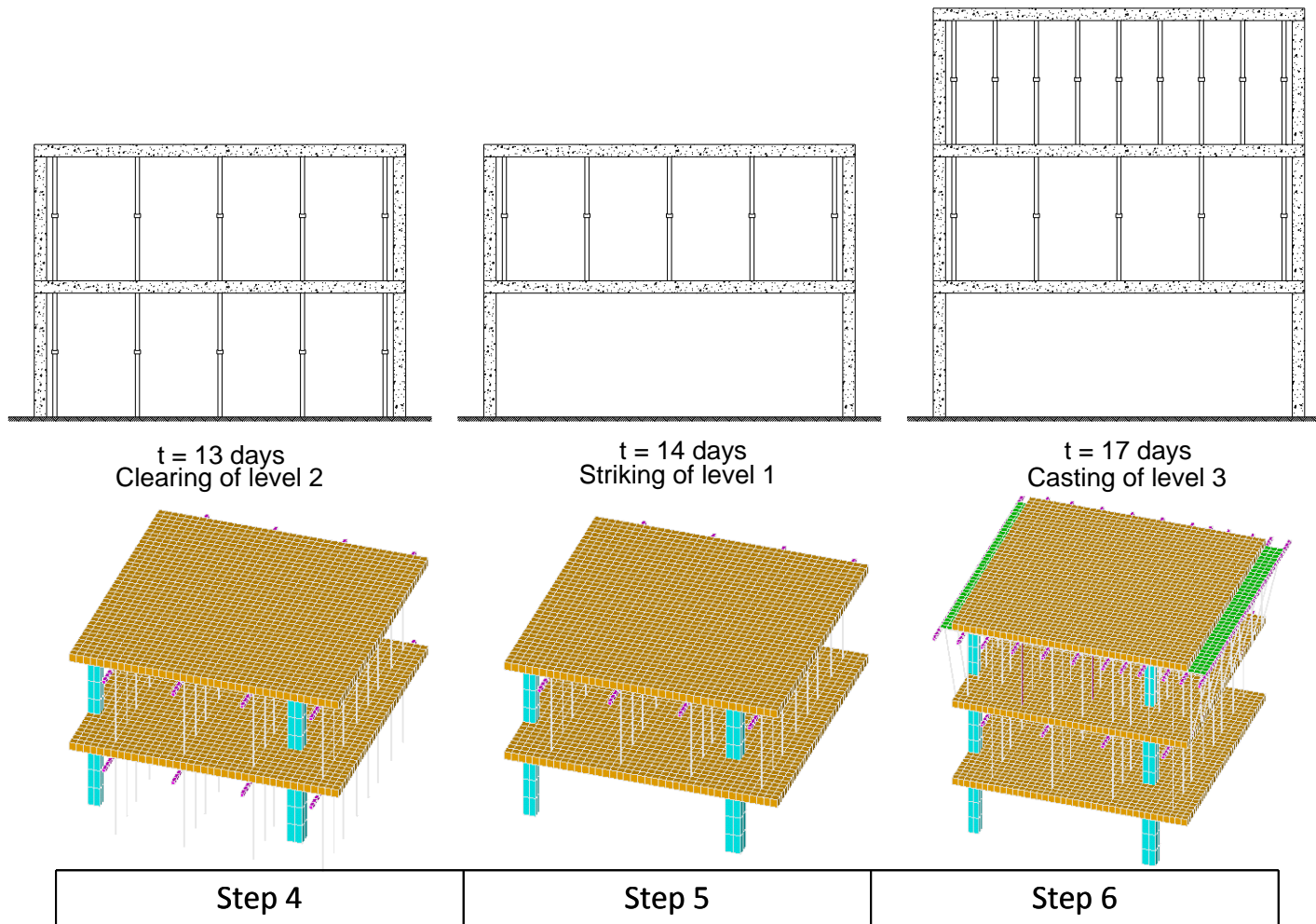
FE Model

Fig. 2. Experimental and FE model

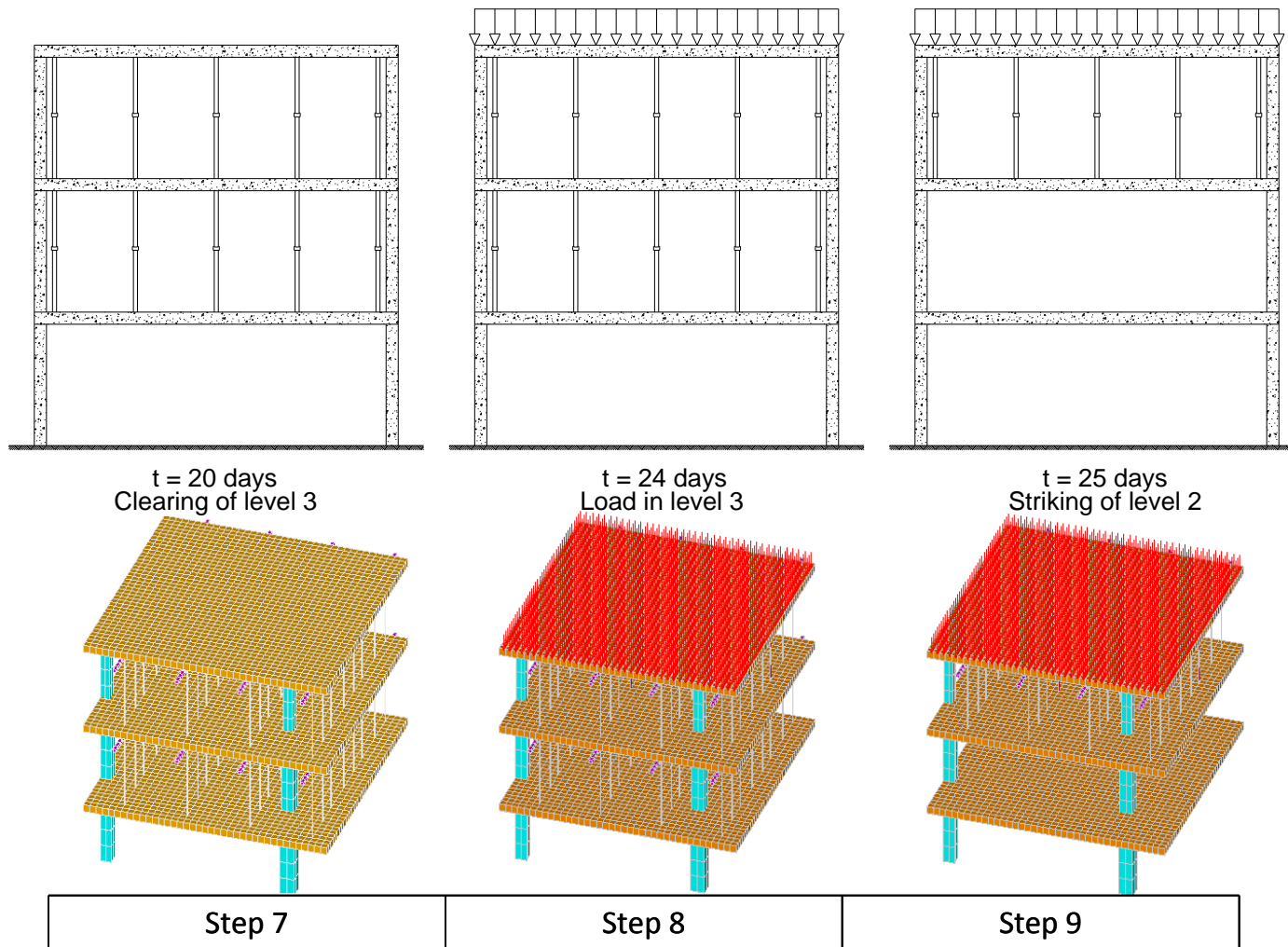




**Fig. 3** Construction phases and load steps of the SCS process (1)

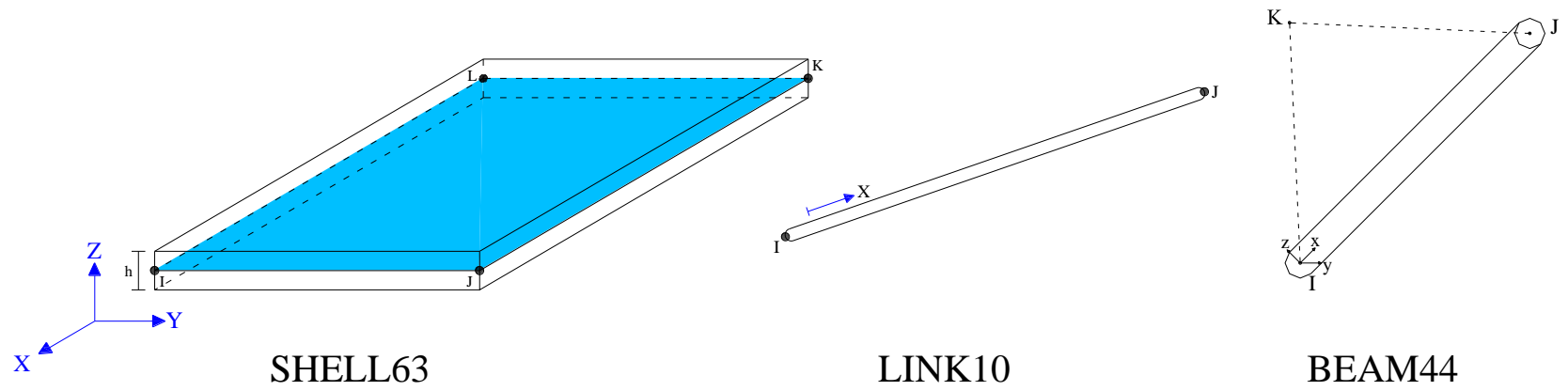


**Fig. 4.** Construction phases and load steps of the SCS process (2)



**Fig. 5.** Construction phases and load steps of the SCS process (3)





**Fig. 6.** Finite elements used in the model

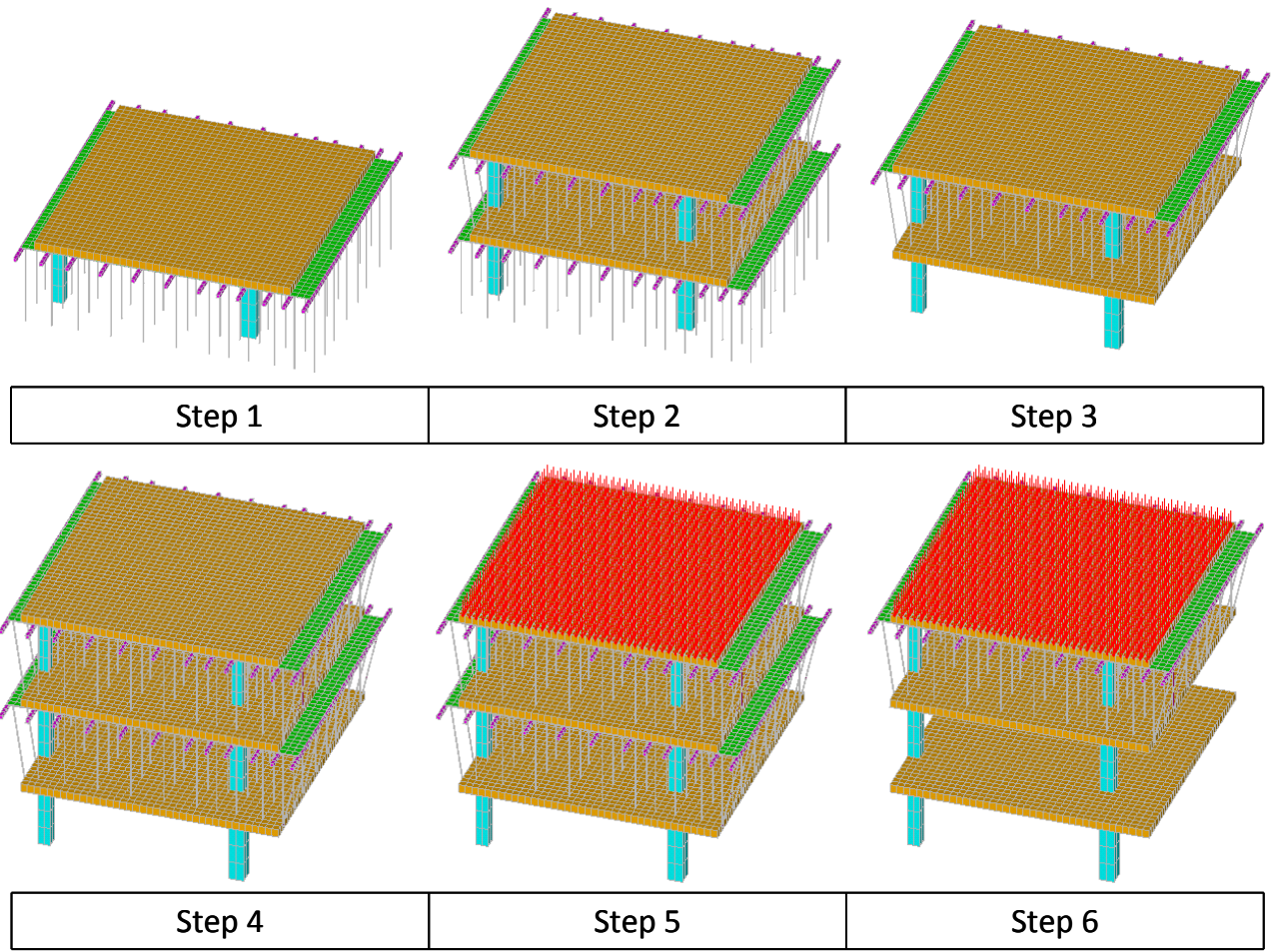
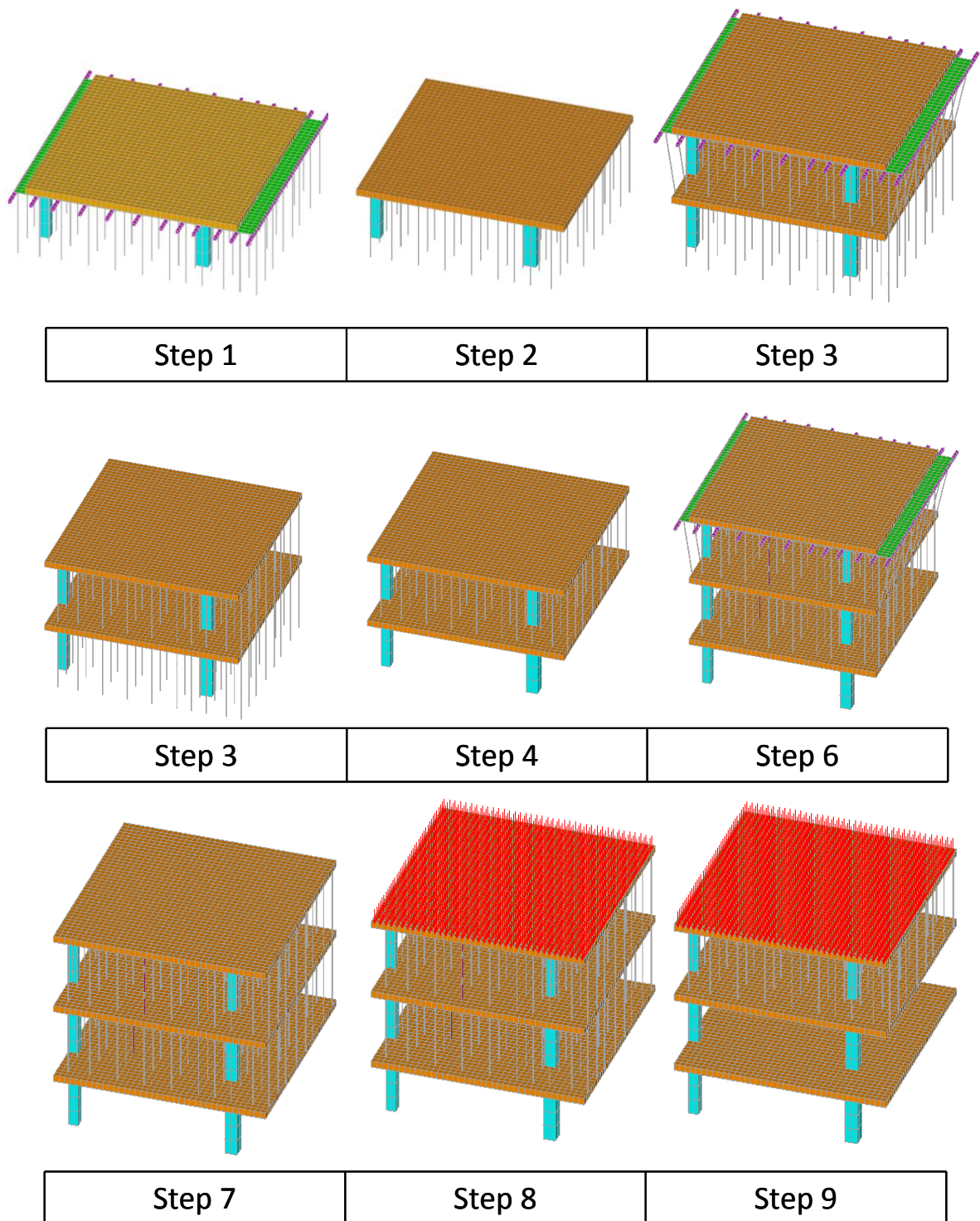
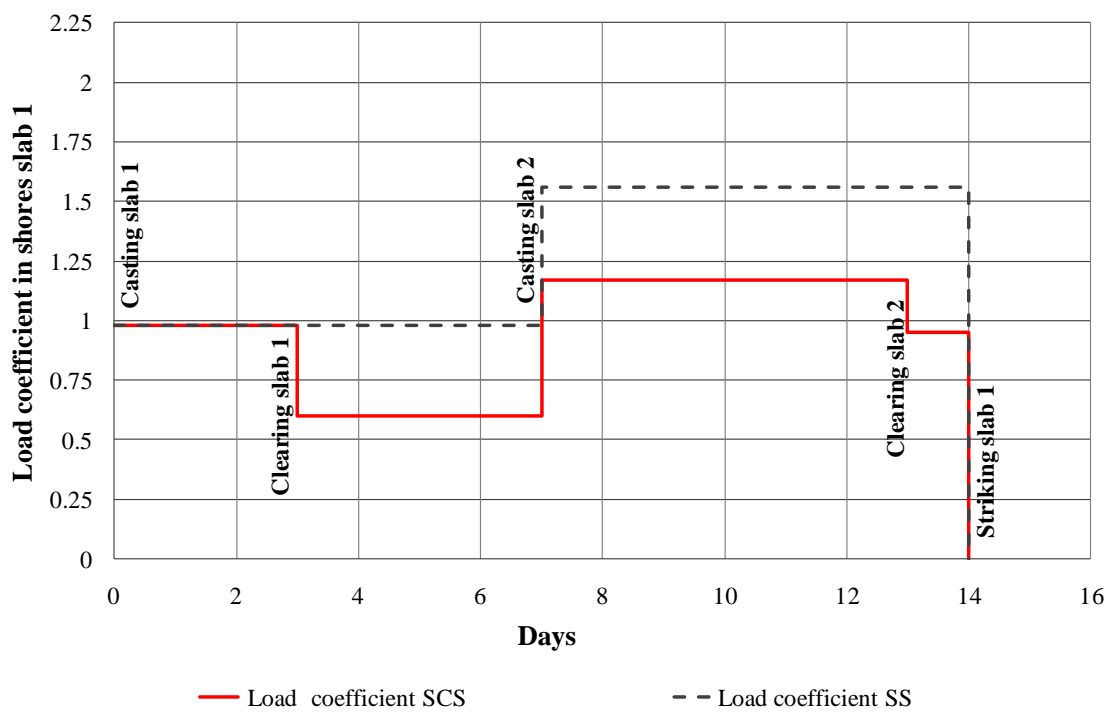


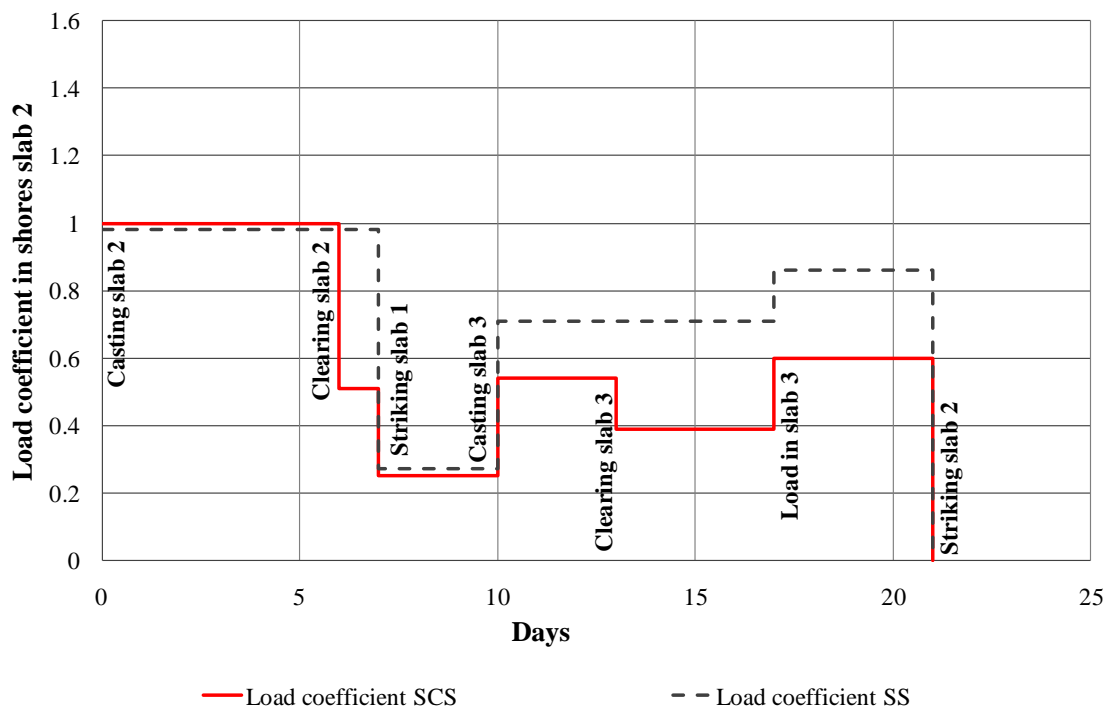
Fig. 7. Construction phases and load steps of the SS process



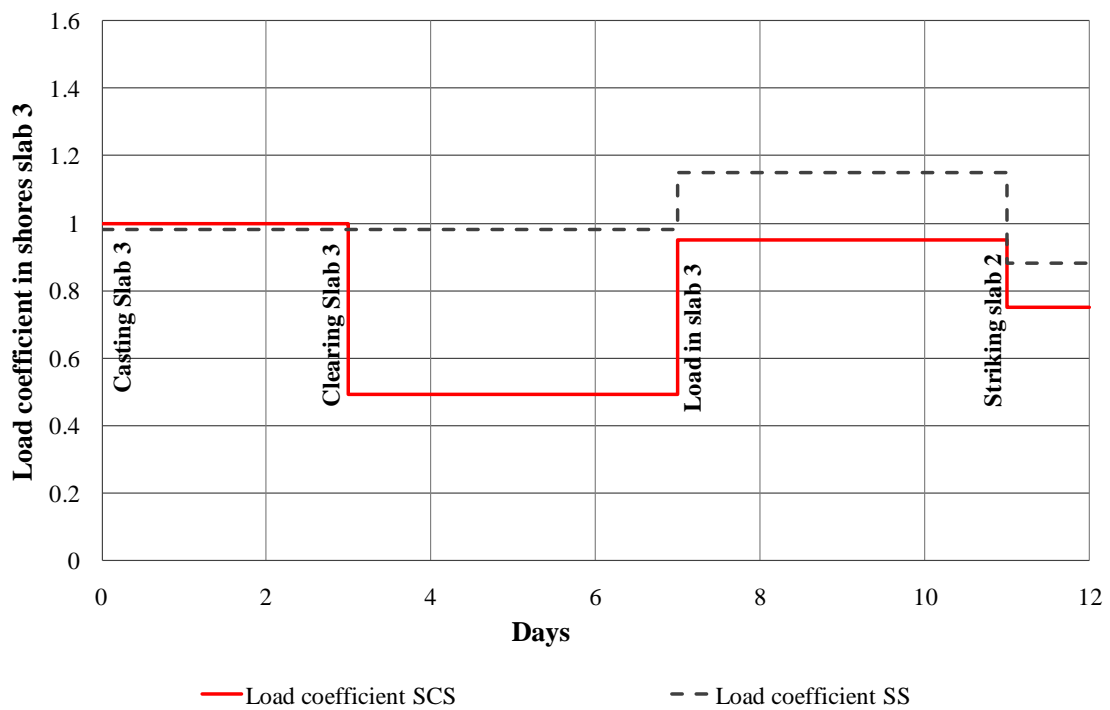
**Fig. 8.** Construction phases and load steps of the SRS process



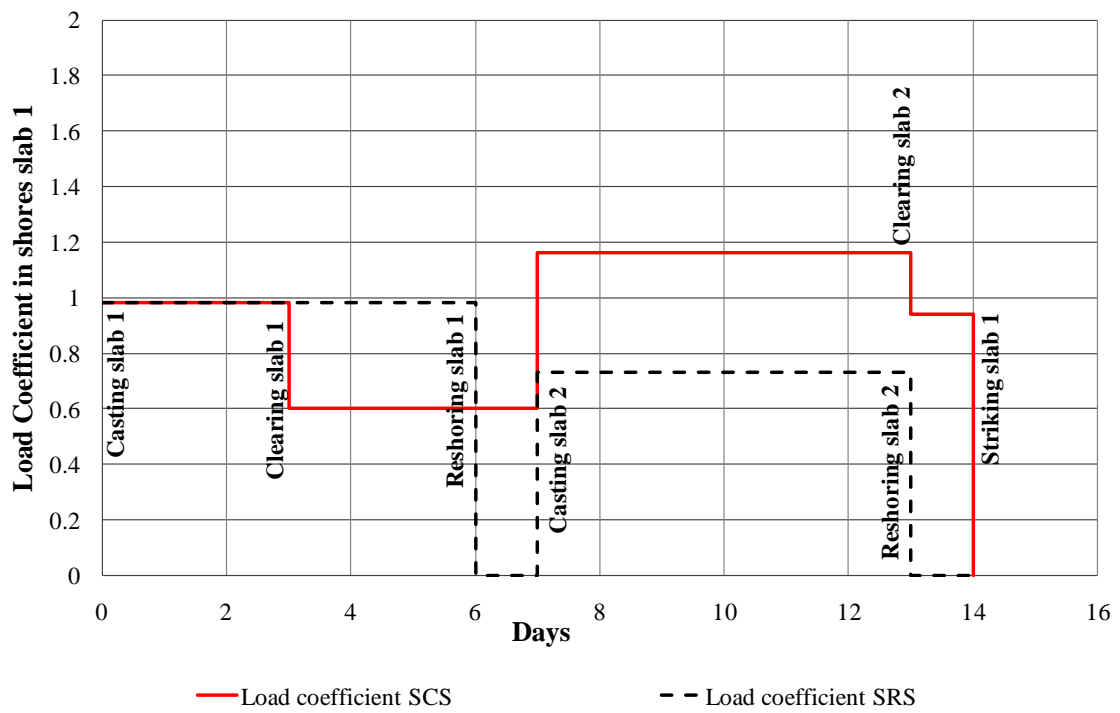
**Fig. 9.** Comparison of SCS and SS processes (Load coefficients in shores supporting level 1)



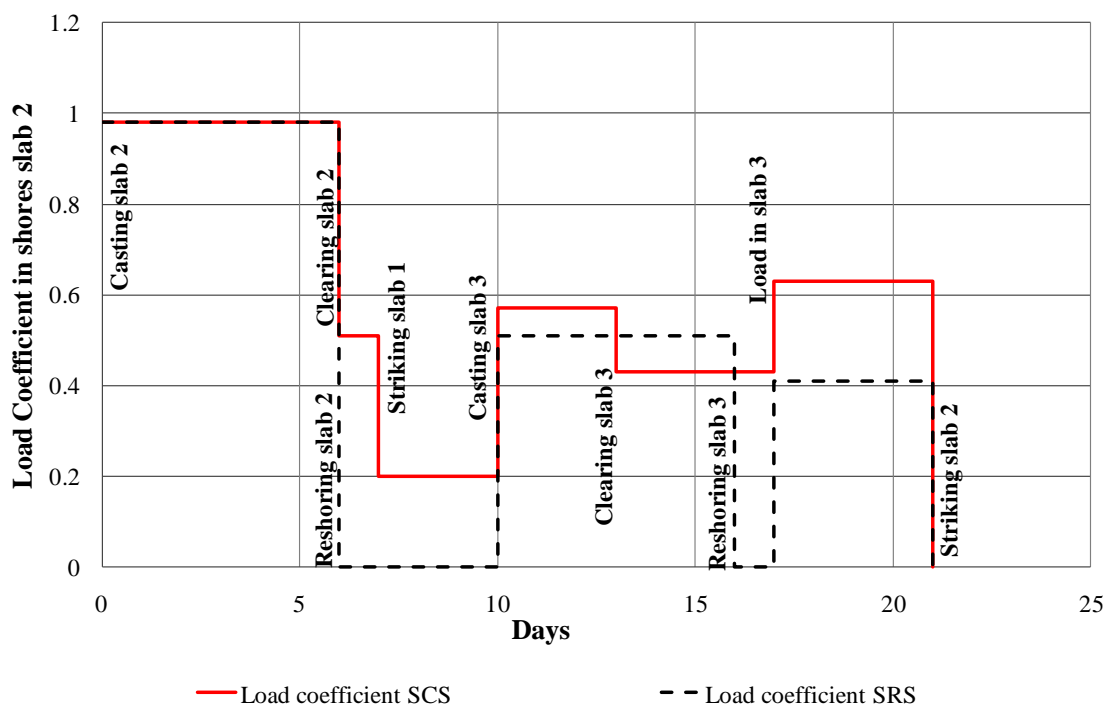
**Fig. 10.** Comparison of SCS and SS processes (Load coefficients in shores supporting level 2)



**Fig. 11.** Comparison of SCS and SS processes (Load coefficients in shores supporting level 3)

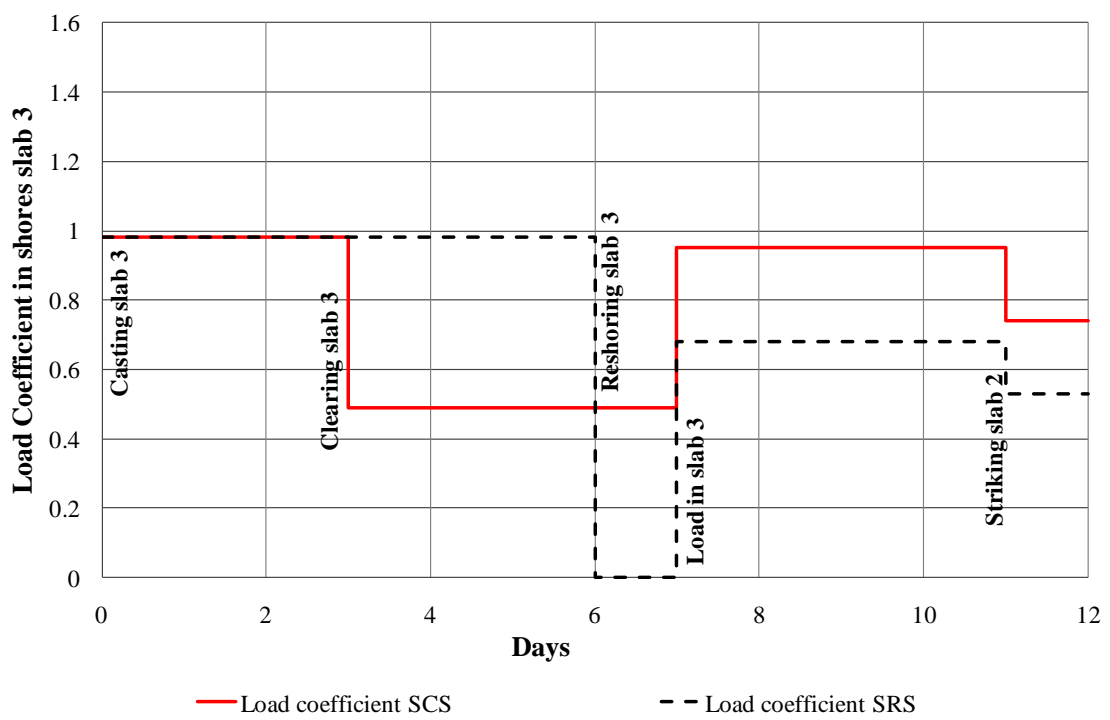


**Fig. 12.** Comparison of SCS and SRS processes (Load coefficients in shores supporting level 1)



**Fig. 13.** Comparison of SCS and SRS processes (Load coefficients in shores supporting level 2)





**Fig. 14.** Comparison of SCS and SRS processes (Load coefficients in shores supporting level 3)