

Coupling of prestressing tendons in segmental construction

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Summary

The increasing propensity for building continuous p.c. structures leads to the need of using in an extensive way prestressing tendons couplers and/or anchorage devices, what's more they're quite often located on construction joints. The presence, in those regions, of high compressive stresses, that can change during the evolution stages, localized in narrow areas, gives rise to non planar deformation states on the coupling surfaces.

These deformation systems also change in time because of differential creep due to the high spatial variability of the stress state.

It's well known that in such conditions wide cracks are likely to rise along construction joints deeply sapping the structure's durability, leaving the prestressing tendons exposed to aggressive agents attacks too.

A satisfactory performance level in these zones is achieved by means of a careful evaluation of the stresses evolution and the design of a proper ordinary reinforcement to control cracks width. A second ruling variable can be the total compression acting on the joint.

A systematic and parametric study of such effects has been carried out in this paper, taking into account the fundamental variables like geometry, local stress state and its evolution and overall stress state.

1 Introduction

Modern building techniques of prestressed bridges ask for the use of tendons couplers and/or the splitting of prestressing in regions inside the structure.

High stresses localizations, bound to evolve in time according to the construction sequence and to concrete creep, arise within the structure as a consequence of this construction procedure. In the same regions take place imposed deformation systems that can lead, combined with the other external actions, to the opening of the joints.

We will analyze some typical cases underlining the effect of mechanic and geometric variables that, with the building sequence, significantly influence the structural response.

The analysis, theoretical and experimental, of the stress and strain state nearby tendons couplers has been approached in the past by a relevant number of researchers [Stone (feb.-1984)], [Stone

(jun.-1984)] and has lead to the definition of consolidated design rules, quoted in the most recognized design codes [Ceb (1993)], [AASHO(1983)], [ACI (1989)], [EN 1992-1-1 (2003)].

On the other hand, the studies and the following relapses in the design world of structural effects induced by couplers and by tendons even if empirically started in a recent past [Leonhardt (1979)], still find open a wide debate in the pertinent scientific field [Seible (1986)], [Seible et al. (1986)], [Picard (1995)], [Picard (2000)], [Byung].

Meanwhile the importance of the subject is brought to attention by the inspection results on the bridges with coupled tendons [Der Bundesminister fuer Verker, Abteilung Strassenbau (1982)], that have shown a frequent presence of wide cracks in regions nearby couplers, often followed by corrosion and damage of prestressing tendons.

The current lack of a methodological study that faces in a systematic way the phenomenon complexity has brought to the indication in the most developed international design codes of merely empirical rules [Eurocode 2-2 (2003)].

The screening of the field bibliography, as numbered previously, has highlighted the following weaknesses in the previous researches:

- Not taking into account real construction methods, related to a clearly identifiable temporary sequence in a reference time interval.
- A not systematic analysis of the effects of concrete creep, that, in general, in presence of imposed deformations, can damp the peak values of stresses evaluated by means of linear elastic analysis. Only in papers of Seible (1986) and Seible et al. (1986) creep is taken into account, but only with regard to the local effect of prestressing loss between the tendon and the coupler, whose magnitude, numerically evaluated, turned out to be sensibly reduced in reality.

Scope of this paper is the definition of proper analysis methods and phenomenon modelling, following the observations written above. A first synthesis evaluation of the obtained results has the aim of better heading the future works, whose results should allow to write design rules able to grant the performance level required by the structure, even in the regions where there're particular discontinuities.

2 Analysis procedure

The aim of the numerical analysis, exposed in the following, is the investigation of the stress and strain system that arises in the intermediate anchorage zones and in the coupling zones of prestressing tendons.

It can be seen at first sight that stresses and strains depends on the structure cross-section geometry, but it's also clear that the zone interested it's the one in the close proximity of tendons anchorages and/or couplers.

Grounding on this idea, we examined the case of tendons coupled or anchored in the webs of a box shaped bridge beam, and, for working easiness, the analysis affected only a portion of the web, as it could be completely disjointed from the structure.

Moreover, as we intended to study in detail the effects of the presence of coupling devices, we considered only the actions induced by the prestressing forces, supposed to be constant in time and not subjected to the classical well known losses.

We also neglected the effects of other permanent and variable actions. A justification of such starting hypothesis is expressed in the following points:

- The advisability of analyzing in a separate way the phenomenon of interest avoiding mixtures with other well known ones.

- The localization of couplers in regions where the internal actions induced by permanent actions have little magnitude.
- The possibility of using the superposition principle to evaluate the global effects starting from the single ones as we work in serviceability conditions (that is in linear field)

Creep has been modelled according to the constitutive laws given in Model Code 1990 (1993) and to the methods suggested by the acknowledged field bibliography [Smerda (1988)], [Bazant (1988)], [Findley (1989)], [Bazant (1986)], [Bathe (1996)].

We supposed to lie in the linear creep field, even if, to tell the truth, in the regions behind anchorage plates the stresses turn out to be far over the limits of linear creep. It should be observed that, on the other hand, in those regions of limited extension, the presence of detail reinforcement, placed to limit bursting and spalling, ends up to rise noticeably the concrete strength.

The concrete constitutive law in the analysis field has been chosen as linear elastic and symmetric, so whenever high tensile stresses appear a non linear analysis shall be required.

The variables taken into account in this study are listed as follows:

- 1) Prestressing force magnitude;
- 2) Number of coupled tendons in a cross section over the total number of tendons in that section;

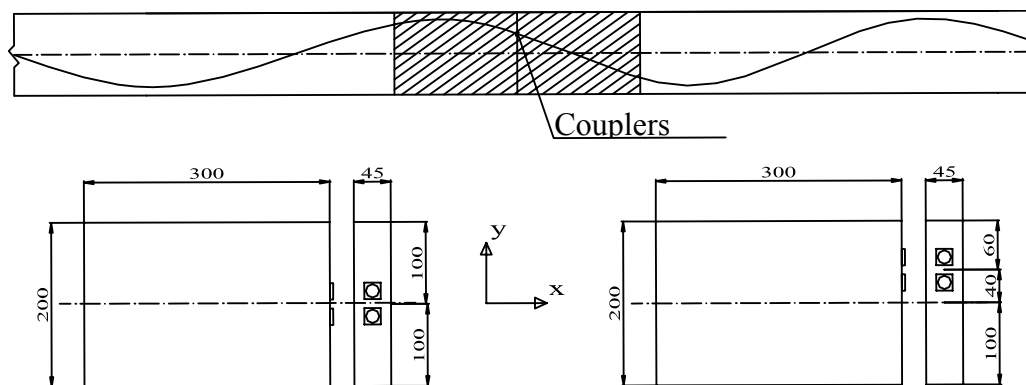


Fig. 1: Model geometry

- 3) Vertical placing of tendons' anchorages and/or couplers.;
- 4) Time intervals of tensioning and retensioning;

In detail the following situations has been studied:

- a) Two values of the prestressing force:
 - i) Fifteen 0.6" strands tendons stressed to 1350 MPa for a total of 2815 KN per tendon, generating an average compressive stress in concrete of 6.25 MPa.
 - ii) nine 0.6" strands tendons stressed to 1420 MPa for a total of 1776 KN per tendon, generating an average compressive stress in concrete of 3.95 MPa.
- b) Two different positions of the resultant prestressing force (fig.1)
 - i) Baricentric prestressing
 - ii) Prestressing with a vertical eccentricity of 40 cm from section barycentre.
- c) Two different ratios between coupled tendons in the joint and total tendons crossing that section
 - i) 100% : two coupled tendons over two total tendons
 - ii) 50% : one coupled tendon and one continuous in the joint.

For what concerns tensioning and subsequent retensioning the following hypothesis has been taken (fig. 2):

- 1) named as $t=0$ the casting time of the 1st part of the web, it is tensed at time $t_1=14$ days;
- 2) At time $t_2= t_1+14$ days= 28 days the second part of the web is cast;
- 3) At time $t_3= t_2+14$ days= 42 days the second part of the web is tensed (in a first case by the coupling of both the tendons, in the second case with only one tendon continuous in the joint between part one and two)
- 4) In the case with 50% coupled tendons, at time $t_4=t_3+14$ days= 56 days the third part of the web is cast and at time $t_5= t_4+14$ days= 70 days the tendon coupled on the joint 1-2 is tensed.

In any case, the mathematical model, as shown in fig.1, covers a portion of the web straddling the joint 1-2 of a length such that the stresses diffusion regions could be considered as completely exhausted.

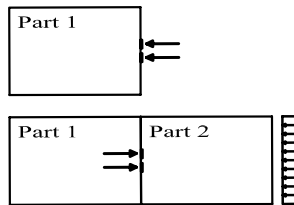
This web portion is been isostatically bound to the exterior world.

The loading sequences for the examined cases are pictured in fig.2.

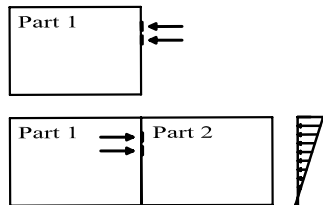
The analysis has been divided in suitable time steps to get increments of the creep factor ϕ less than 0.10 for the younger concrete, that is subjected to the highest creep.

The Young modulus variability of concrete in time between different casting has also been taken into account. For the pertinent evolution relationship Model Code 1990 has been followed.

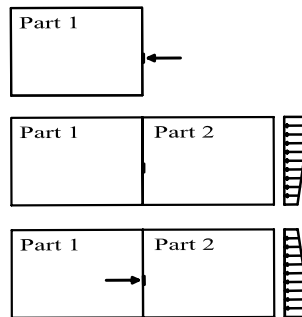
Loading models for
centred prestressing
and two coupled
tendons.
Models at times:
 $t = 14$ days
 $t = 42$ days



Loading models for
eccentric prestressing
and two coupled
tendons.
Models at times:
 $t = 14$ days
 $t = 42$ days



Loading models for
centred prestressing and
one coupled tendon.
Models at times:
 $t = 14$ days
 $t = 42$ days
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Loading models for
eccentric prestressing
and one coupled tendon.
Models at times:
 $t = 14$ days
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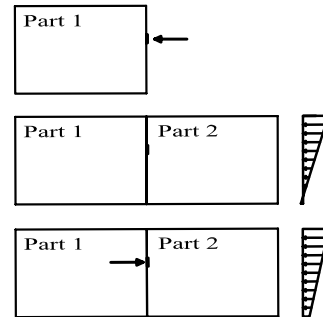


Fig.2 : Loading models

A limit case is an anchorage placed in the joint without a following stress unloading; that is the limit situation for a coupler of a very long tendon that, because of friction, loses almost all its force before the coupling zone. It is clear that this is an asymptotic situation, but it's relevant to define the effect of a prestressing force variation in the coupling zone, born as a consequence of the tensioning of the coupled tendon.

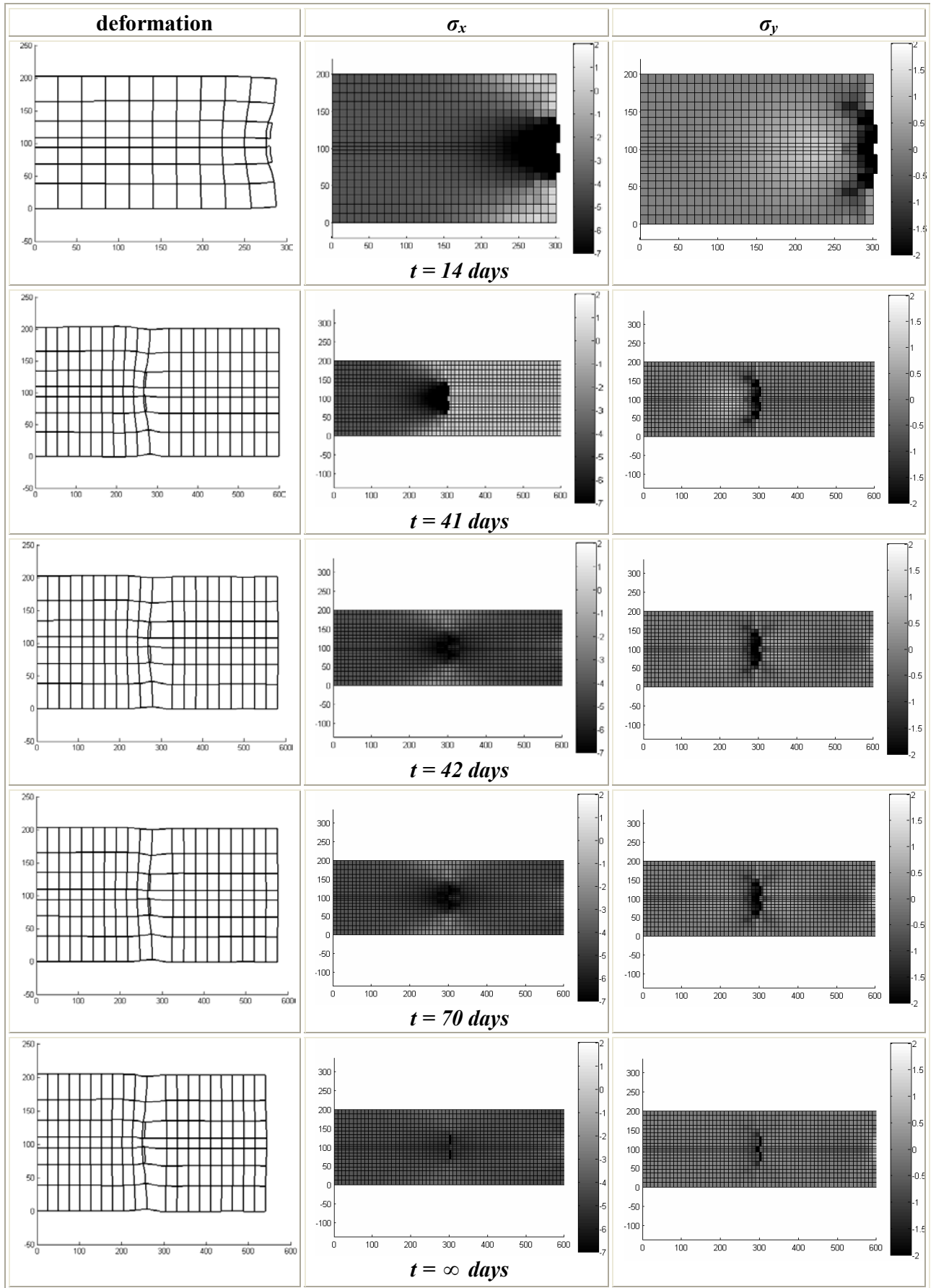


Fig. 3 : Baricentric prestressing, two coupled tendon over two

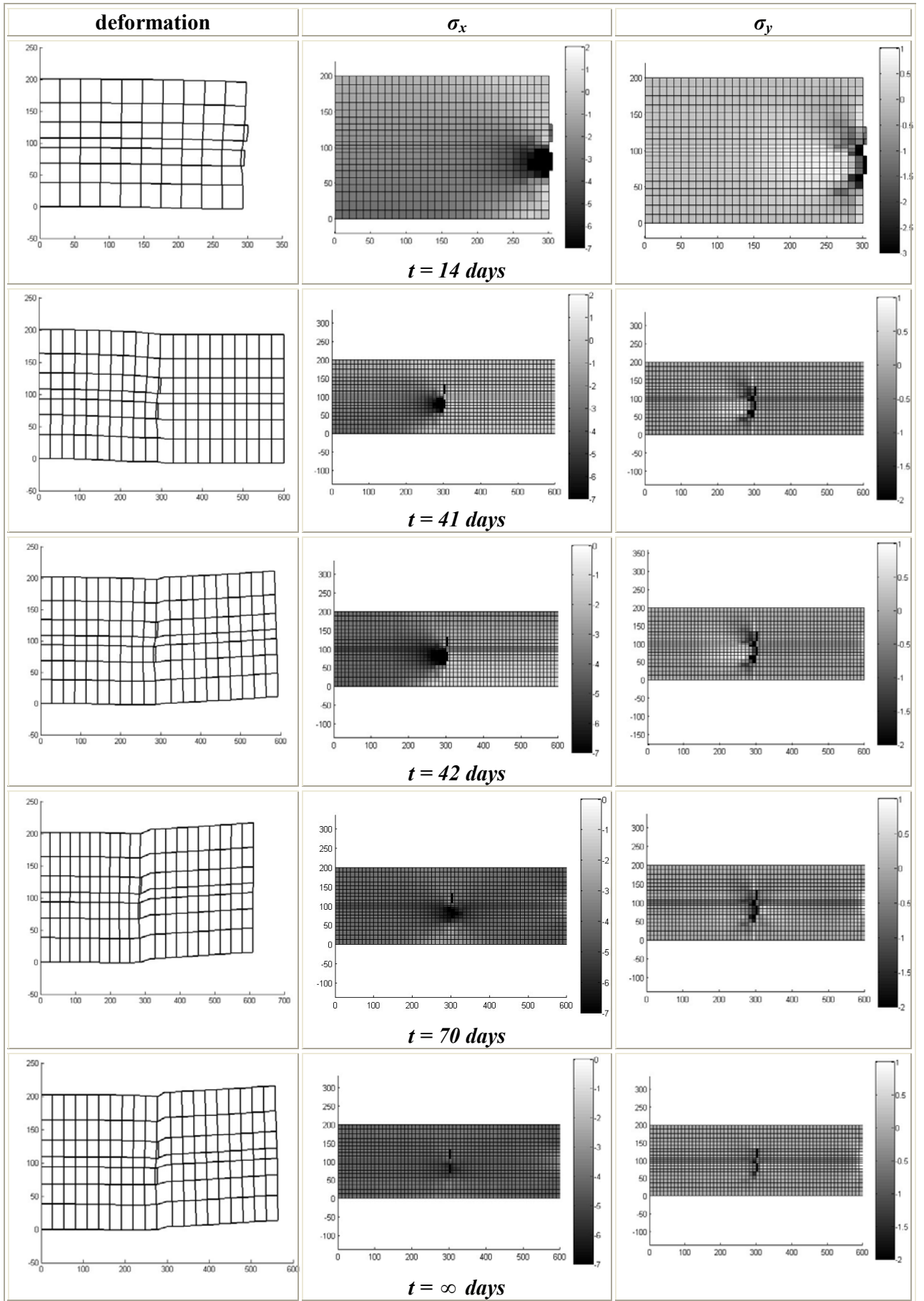


Fig. 4 : Baricentric prestressing, one coupled tendon over two

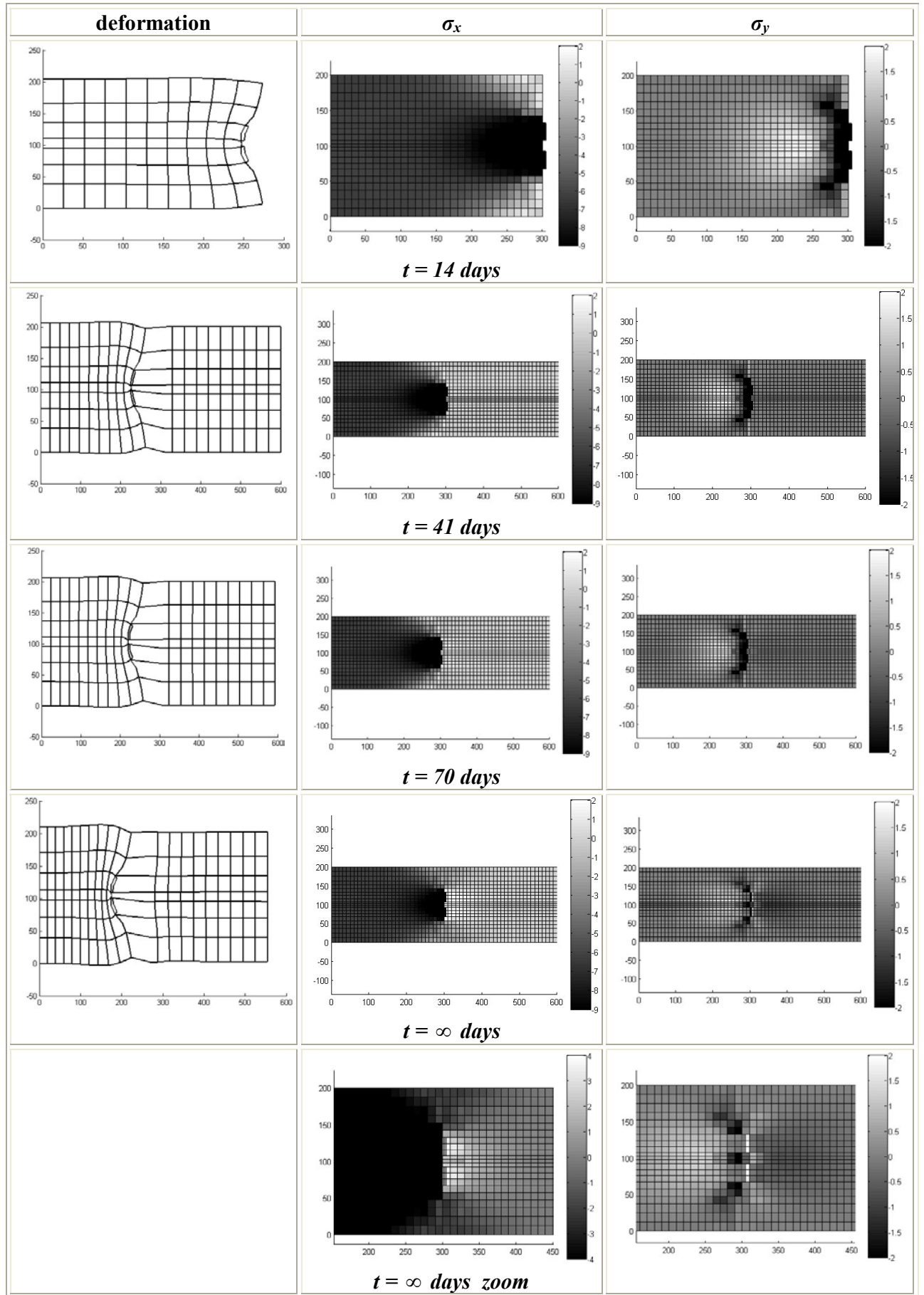


Fig. 5 : Baricentric prestressing, two anchored tendons over two

3 Numerical analysis results

Figure 3 shows the deformation and the stresses (longitudinal and transverse) pertinent to the time phases described in point 2 plus time equal to infinite for the case of centred prestressing ($\sigma_{av}=6.25$ MPa) and 100% of coupled tendons.

The review of the shown parameters leads to the following considerations:

- In the time period from the casting of the second part and the retensioning of the tendons, in the new casting longitudinal tensile stresses, whose magnitude is proportional to the elapsed time, take place. These stresses are caused by the non planar creep component of the deformation of the first part.
- When the retensioning is completed the stresses mentioned above change sign and order of magnitude but the compressive stress near the coupler remain more or less one half of the expected ones.
Bursting stresses can be observed along the transverse direction. After the retensioning they halve in the first part but they born with the same halved intensity in the second part.
It's then evident that reinforcement for bursting should be placed also in the second part behind the coupler.
- Being all of them stresses derived from imposed deformations, the favourable effect of creep tends to damp them sensibly in time.

Figure 4 shows the same parameters of figure 3, but with 50% of coupled tendons in the joint.

The phenomenon presents the same characteristics of the previous case, taken of course in consideration the dissimetries introduced by the tensioning of a tendon only (spalling stresses well visible also in the second part after the retensioning), but the local effects are scaled by 50%. At time infinite the creep brings the structure to a stress state similar to the case of full coupling seen in figure 3 (100% coupled tendons in the joint).

The effect of the eccentricity of the tendons implies the presence of the typical stresses of bending and axial force at time infinite, but the evolution of the phenomenon is the same as in the previous cases.

The average stress produces the same results, obviously scaled in the right proportion.

In every case we can see tensile stresses along the joint able to open it, much more if we consider that there are two different castings. These stresses should be absorbed by a reinforcement able, in terms of collocation and rate of work, to control the crack opening in a range value of about 0.1 mm.

Finally figure 5 shows the case of the tensioning of an intermediate tendon, that is not retensioned. It can be observed how take place very high tensile stresses, that comport the joint opening. Moreover, in this case, as we're dealing with stresses generated by a concentrated force and not by imposed deformations, creep doesn't damp the phenomenon, but enhances it as time goes by.

It's then necessary to place a high level of detail reinforcement and rely also on the average distributed stress present in the other zones of the structure in order to control cracks width.

4 Conclusions

The analysis illustrated in the previous paragraphs let us know the main parameters that rule the structural behaviour in presence of couplers or anchorages on intermediate sections of the structure.

Creep takes a different part between the two limit cases, favouring stress damping in case of coupling and enhancing the stress state in case of intermediate anchorage.

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