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COMPARISON BETWEEN A NEW EXTERNAL CODE COUPLER GC+ EXTENDED IN NON-LINEAR DYNAMICS AND ABAQUS/CO-SIMULATION

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Abstract. *The aim of this work is to propose a comparison between our new GC+ external code coupler extended to non-linear cases with the new capability Abaqus/co-simulation which is able to couple Abaqus/Explicit with a Finite Element code Abaqus/Standard (Implicit scheme). The external code coupler available in Abaqus version 6.9 called Abaqus/co-simulation is based on the sub-domain decomposition method named GC method. This method has been proposed by Gravouil and Combescure for Newmark time schemes in linear dynamics and, then, extended to non linear dynamics. First, the GC sub-domain decomposition method and the GC+ method issued from a reformulation of the GC method are presented. Then, the use-case called "Airbus plane panel" which will be used to compare our non-linear GC+ code coupler with the co-simulation method of Abaqus 6.9 is described. Finally, obtained results in non-linear cases are presented and discussed. This work is funded by the European project MAAXIMUS.*

1 INTRODUCTION

The main difficulties of the non-linear transient structural computations lie in the computation costs and the memory requirements for storing the data.

The objective of this paper is to propose a method extended to non-linear cases, which permits reduction of time costs as well as memory necessary to solve the problem. All the paper is based on the use of Newmark time integration schemes with different parameters.

A relevant way in order to considerably reduce computational costs is to use sub-domain decomposition methods. In order to accurately represent impacts phenomena, preserve the stability of the time integration scheme and optimize the finite element structural analysis, it is very efficient to decompose the complete structure into several sub-domains associated with appropriate time step and appropriate mesh element size depending on sub-domains.

Several families of decomposition methods can be identified depending on the way of enforcing the continuity of quantities across the interface. The GC method imposing the continuity of velocities at the interface has been proposed by Gravouil and Combescure for Newmark time schemes in linear dynamics [1] and, then, extended to non linear dynamics [2], explicit non linear dynamics [3], coupling of modal sub-domains [4] and space-time automatic refinement techniques [5]. It has been proved that the GC method can produce some numerical dissipation at the interface between sub-domains. Prakash and Hjelmstad [6] have proposed a more complex algorithm for linear transient dynamics (PH method) without dissipation at the interface and which also enforces velocity continuity at the interface. The velocity constraint is applied on the macro time step, contrary to the GC method applying the velocity constraint on the micro time step. Then, Mahjoubi, Gravouil and Combescure [8] proposed a general method in the case of linear transient dynamics, labelled as MGC method, which ensures that the interface energy remains equal to zero for any time integrator. This method is able to couple Simo, Krenk, Verlet, HHT and Newmark time schemes with different time steps. The MGC method imposes on the macro time step the continuity of the velocities at the interface in a weak sense. The GC method has been recently improved by Batti et al. [12] labeled as GC+ method which is energy conserving as PH and MGC methods. In addition, the formulation of the new algorithm appears much simpler than PH and MGC methods.

In the first section of this article, the algorithm of the GC & GC+ sub-domain decomposition methods will be presented in the case of homogeneous time scale and then, in the case of heterogeneous time scales. Then, we will explain how the GC+ method can be extended to non-linear cases. Furthermore, we will present how to set up an external code coupler based on the modified GC+ method. Finally, an industrial example subjected to crash loads will permit us to compare our coupler with Abaqus/co-simulation (an external code coupler developed in Abaqus v6.9 which is using the GC sub-domain decomposition method).

2 THE GC & GC+ METHODS AND THE GC & GC+ COUPLERS IN LINEAR CASES

First, in the case of an identical time step used for each sub-domain of the global structure, the GC and GC+ sub-domain decomposition methods are the same. The difference between these two methods appears in the case of multi time scale.

2.1 A sub-domain decomposition method with mono time step scale (GC=GC+)

The following explanations aim at highlighting the key points of the method. The main idea of the method is to decompose the solution into two parts (free solution and link solution).

Decomposition into a free part and a link part of the complete solution:

The Finite Element Method used for the numerical simulation of a global structure gives the semi-discrete equilibrium equation in space:

$$M\,a + F_{\text{int}}(u) = F_{ext} \tag{1}$$

where M is the symmetric, definite, positive mass matrix, F_{ext} the external forces and $F_{\text{int}}(u)$ the internal forces, a the acceleration. The whole structure is decomposed into several sub-domains, denoted by the superscript $k = 1,...,s$. In each separated sub-domain k, the equilibrium equation can be rewritten as:

$$M^k a^k + F^k_{\text{int}} = F^k_{ext} + F^k_{link} \quad \forall\{1,...,s\} \tag{2}$$

with F^k_{link} representing the interface loads applied on the sub-domain k under consideration (interface loads), which can be linked to the kinematic constraints on interfaces of the k sub-domain. The kinematic constraint connecting all sub-domains together is written in a global form, for the whole domain:

$$\sum_{k=1}^{s} L^k v^k = 0 \tag{3}$$

where L^k is the constraint matrix for a given k sub-domain. The link force is then obtained by introducing Lagrange multipliers Λ for the whole domain:

$$F^k_{link} = L^{kT}\Lambda \tag{4}$$

2.2 Sub-domain decomposition methods with multi time step scale (GC ≠ GC+)

The GC and GC+ sub-domain decomposition methods become different in the case of multi time step scale. The free problem, the condensed problem at the interface and the link problem are not solved in the same order for the two GC & GC+ methods in the case of sub-domains with different time steps. The difference between these methods is schematically presented in Figure 1 in the case of two sub-domains (a sub-domain A with a large time step and a sub-domain B with a small time step).

These sub-domain decomposition methods are used to build up respective external code couplers. A sub-domain is modeled by a separated FE code whereas the mechanical behavior of another sub-domain of the structure is simulated by another FE code. An external code coupler is used to communicate with the separated FE codes simulating each one a sub-domain of the structure. A coupled FE code solves the free and the link problems of a sub-domain whereas the external code coupler manages the computation of the problem of condensation at the interface. Data exchanges between the external code coupler and the coupled FE codes are ensured by pipes.

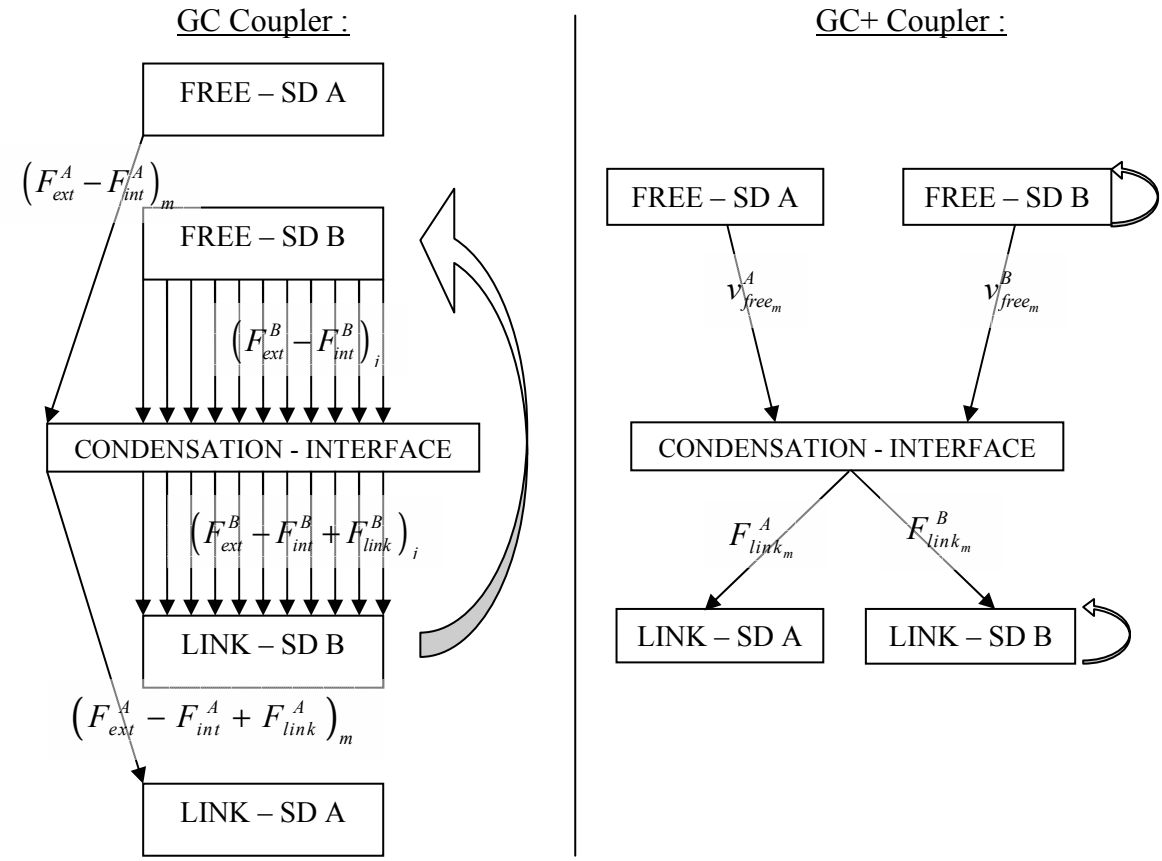

Figure 1: The GC & GC+ couplers.

3 THE GC & GC+ METHODS AND THE GC & GC+ COUPLERS IN NON-LINEAR CASES

First, the GC sub-domain decomposition method presented above already works in the case of non-linearity. So, it is not needed to modify the GC sub-domain decomposition method in non-linear cases.

In this section, we will present the modifications imposed to the previously presented GC+ method in order to be able to extend it to the case of material non-linearities. The case of a coupling of a macro-time step non-linear implicit sub-domain A with a micro-time step non-linear explicit sub-domain B is studied here.

First, a modification of the part of the algorithm corresponding to the non-linear micro explicit sub-domain B is necessary in non-linear cases. This improvement is schematically presented in Figure 2.

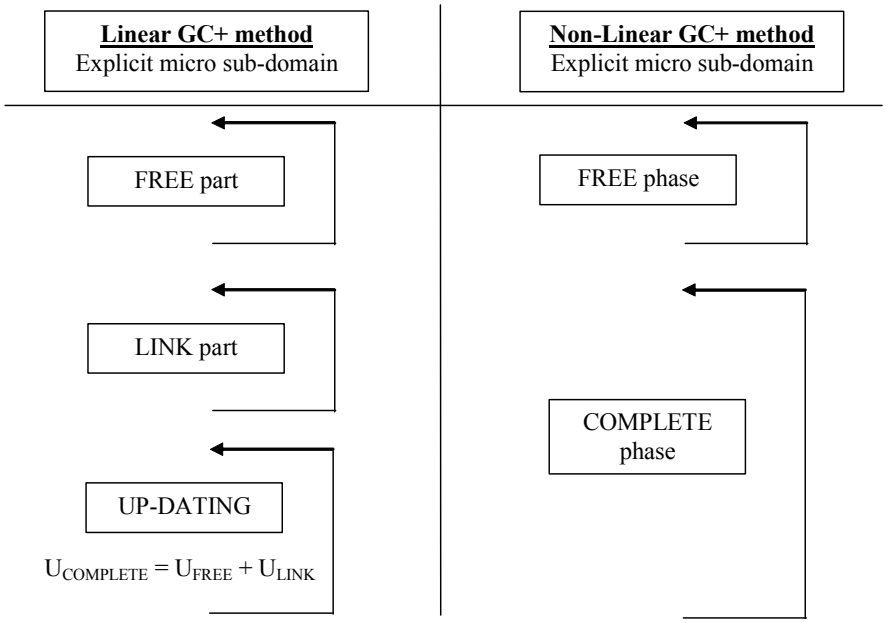

Figure 2: New strategy with GC+ method for coupling a non-linear micro explicit sub-domain.

A complete phase used in the new method permits to avoid the addition of the free and the link parts which is valid only for linear cases and not for non-linear cases.

Secondly, the modification of the part of the algorithm corresponding to the non-linear macro implicit sub-domain A is now presented. The difficulty for an implicit scheme in order to compute non-linearities is to implement an iterative scheme such as Newton algorithm in order to ensure the balance at the end of the implicit time step. At the end of a macro implicit time step, the complete solution has to satisfy a stopping criterion and if it is not the case, a new computation of the macro sub-domain A is done. So, data exchanges between the coupled codes and the external code coupler for a non-linear GC+ external code coupling must be adapted with the stopping criterion of the Newton algorithm.

4 COMPARISON BETWEEN THE EXTERNAL CODE COUPLER GC+ EXTENDED IN NON-LINEAR DYNAMICS AND ABAQUS/CO-SIMULATION

A comparison for a transient non-linear dynamics problem is proposed between the new GC+ non-linear external code coupler and the code coupler available in Abaqus v6.9 named "Abaqus/Co-Simulation" which is built by using the GC sub-domain decomposition method. In this section, a non-linear dynamics application is considered. It is the Airbus plane panel used as Maaximus use-case with an open interface with compatible mesh at the interface between the two chosen (non-linear macro implicit & non-linear micro explicit) sub-domains.

Our GC+ coupler extended in non-linear cases couple here the code CASTEM 2009 developed at the Commissariat à l'énergie atomique (CEA).

A simplified Airbus plane panel is a case of interest for engineering application in the aeronautic field. A panel is a part of a plane's barrel. The panel is composed by a skin, frames and stiffeners. The panel is pinned along the two small sides of the contour. Charge is applied on the very small zone at the centre of the panel. The mechanical behaviour is assumed to be perfectly plastic for each component of the panel. The application example computed with

external code coupling using two (Macro-implicit & micro-explicit) sub-domains is presented in Figure 3.

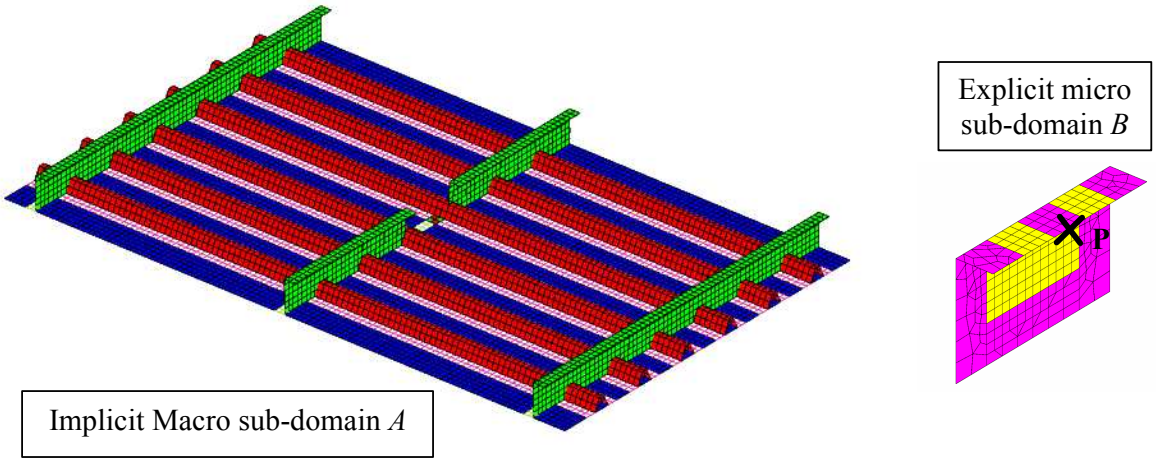

Figure 3: Definition of the two sub-domains composing the Airbus panel structure.

The displacements at point P (see Figure 3) obtained by our GC+ external code coupler extended in non-linear cases and obtained by a classical mono-domain explicit code are compared in Figure 4.

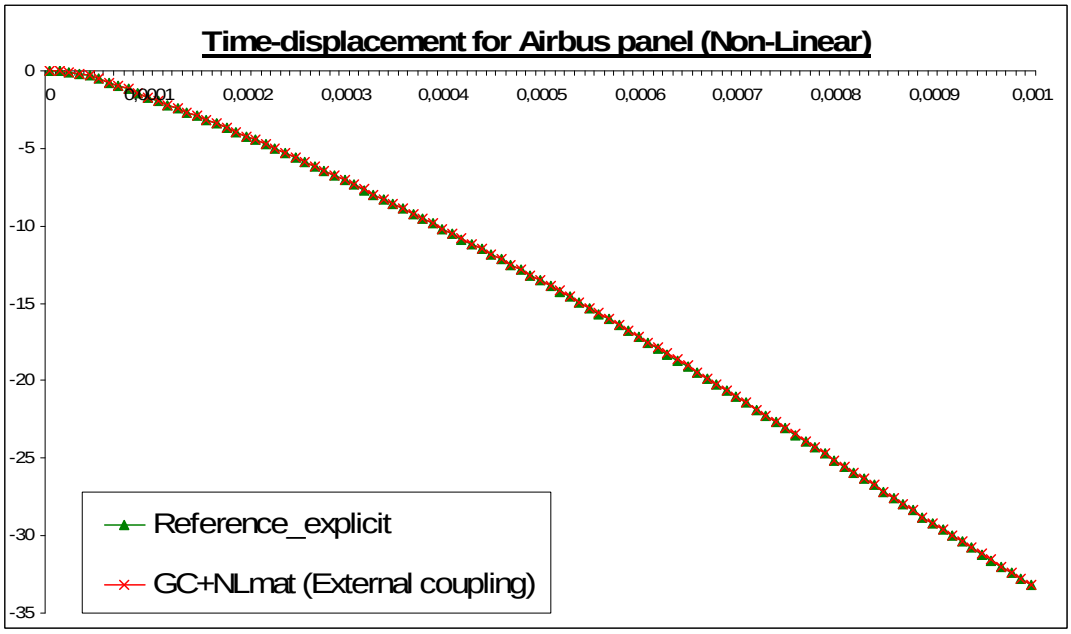

Figure 4: Comparison between the GC+ code coupler and the explicit mono-domain computation responses in terms of displacements.

As shown in Figure 4, the prediction ensured by computation done by our non-linear GC+ external code coupler compared to a classical solving using a unique micro explicit FE code used as Reference is very good in terms of maximal vertical displacement response.

The results in terms of displacement at point P given by a classical unique solving Abaqus/Explicit and by the new capability Abaqus/co-simulation (Abaqus/Standard coupled with Abaqus/Explicit) for the Airbus plane panel numerical simulation are compared in non-linear case in Figure 5.

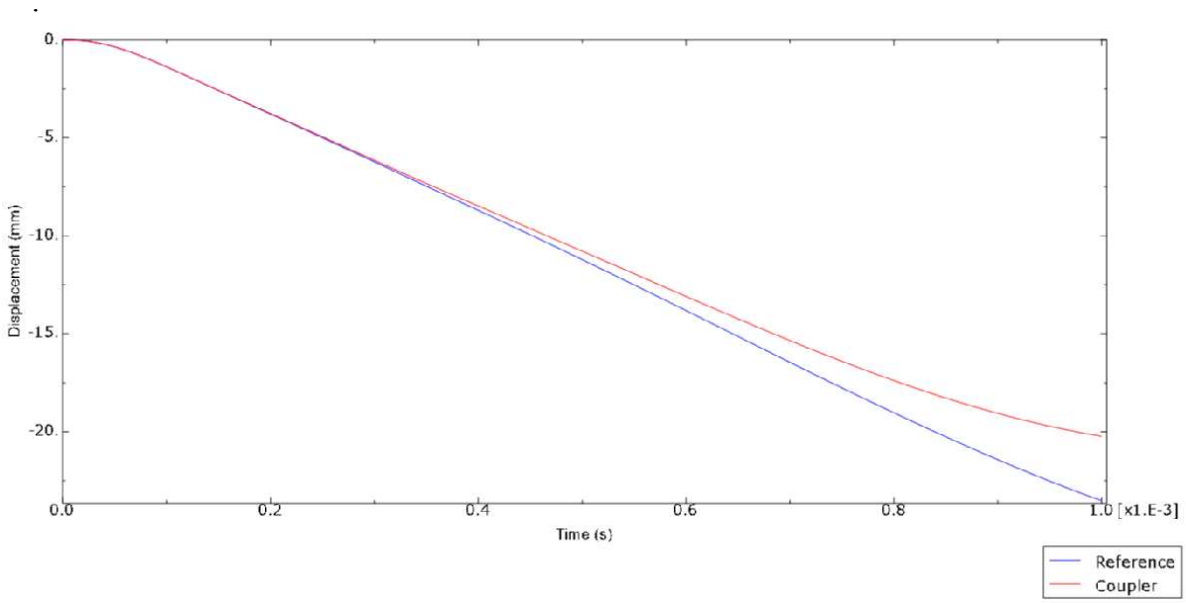

Figure 5: Comparison of results in terms of displacement obtained by the coupler called Abaqus/co-simulation and by a classical explicit computation (Non-linear case).

Contrary to the GC+ code coupler, we can observe in Figure 5, that the prediction in terms of displacements given by Abaqus/co-simulation compared to the reference is not good. At the beginning of simulations, the two obtained time-displacement curves are very close but as long as time passes, we can see that the difference between the two curves increases regularly.

5 CONCLUSION

In this article, we have presented the key equations of the GC &GC+ sub-domain decomposition methods in the case of a same time step used for all the sub-domains composing the structure. Moreover, we have described a linear external code coupler using the GC+ sub-domain method in the case of multi time scales. Then, the extensions of the GC+ sub-domain decomposition method and of the GC+ external code coupling to the non-linear cases have been proposed. The non-linear GC+ external code coupler manages to couple a macro non-linear implicit FE code with a micro non-linear explicit FE code. Finally, a comparison of this GC+ code coupler with Abaqus/Co-simulation which is able to couple Abaqus/Explicit with Abaqus/Standard and based on the GC sub-domain decomposition method.

It seems that Abaqus/Co-simulation available in Abaqus 6.9 should be used with care for displacement responses in material nonlinear case. The proposed GC+ code coupler is already able to couple Castem2009 and Europlexus finite element codes and a possible perspective to this work can be to generalize it for other existing commercial finite element codes (Abaqus, Aster …).

6 ACKNOWLEDGEMENTS

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