Mixed Dimensional Hierarchic Partitioned Nonlinear Analysis of Frames with Masonry Infill

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Abstract

This paper presents the mixed-dimensional partitioned nonlinear analysis of framed structures with masonry infill. The analysis method is elaborated with the help of an example frame made of steel sections with brick masonry infill. The structure is partitioned in a hierarchic manner using a domain decomposition technique based on dual partition super-elements. The frame is subjected to a load increasing constantly on its free end. The final deflected shape after the analysis is presented that shows a separation occurring at the location of the mortar between bricks. Contours showing plastic work flow at the interfaces are also presented.

Keywords: Masonry Infill, Hierarchic Partitioning, Parallel Computation, Mixed Dimensioning, Nonlinear Analysis

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INTRODUCTION

The purpose of engineering computations is to chart out the response of physical systems to certain actions, generally called loads. This information is then used for making or justifying engineering decision (Szabo and Babuska, 1991). From among several mathematical and computational techniques available for this purpose, the finite element analysis method is the most widely used mainly because of its capacity for solving large size problems of a wide range (Huebner et al. 2001).

Apart from the mistakes made by users of finite element analysis tools, there are three main sources of error in finite element method (Cook et al., 2002), as listed below:

- Modelling/Formulation Errors
- Discretization Errors
- Numerical Errors

The numerical errors depend upon the mathematical precision of the computing machine being used and hence further discussion on its implications and rectification is out of the scope of this paper. Discretization errors are controlled mainly by increasing the number of elements or using elements with higher order shape functions. Modeling errors, on the other hand, can be addressed, at least in part, by using higher dimensional elements as well as incorporating material and geometrical nonlinearities in the FEA formulations so as to capture the real structural response.

When further accuracy in finite element analysis is sought by diminishing the above-mentioned discretization and modeling errors through the use of more elements with higher order shape functions and higher dimensions; the problem size from computational point of view increases enormously and often times it becomes practically impossible to perform such analyses (Mata, Barbat&Oller, 2009; Yue, Fafitis, &Qian, 2010; Spacone& El-Tawil, 2004). The problem can, however, be effectively addressed in two different ways. In the first method, the problem may be decomposed in partitions and run simultaneously in parallel on several processors. In the second method, the non-critical parts of the problem can be analyzed using the simplified models whereas the critical parts can be modeled in detail. This second approach can be termed as 'part simplification'.

The domain decomposition method for the partitioned parallel nonlinear analysis of structures was recently developed at Imperial College London as part of the PhD study of the first author (Jokhio, 2012). This method of domain decomposition was based on the concept of displacement frame method and introduced dual partition super-elements (Jokhio and Izzuddin, 2013). This paper is focused on the demonstration of the applicability of this domain decomposition method to the analysis of frames with masonry infill. These are the types of structures that are normally dealt with by making several simplifications. For the analysis of such structures where the frames have masonry infill, the masonry is generally taken as a super-imposed load only and its role in the performance of the structure is ignored. This is done because of the impracticality of such an analysis. The issue, however, has been addressed in this study and through the following example, it is demonstrated that the detailed analysis of such structures has been made possible.

Frame with Masonry Infill

The case study presented here relates to a steel frame with masonry infill, as shown in Figure 1. The frame members consist of rectangular solid steel cross-sections, and the masonry infill consists of bricks as illustrated in Figure 2.

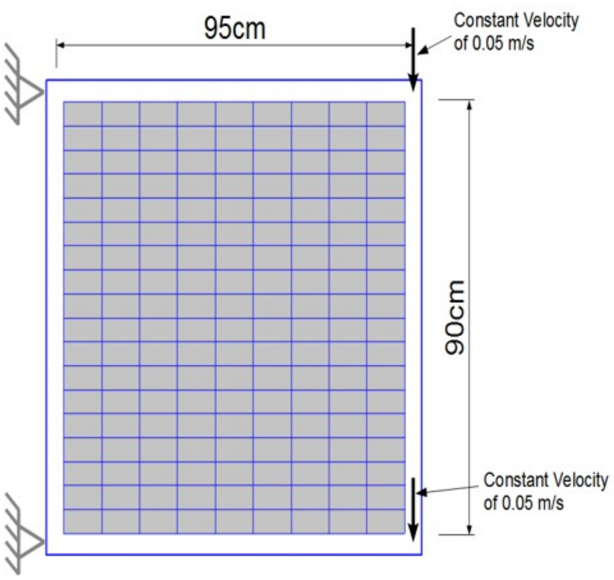

Figure 1: Frame with masonry infill

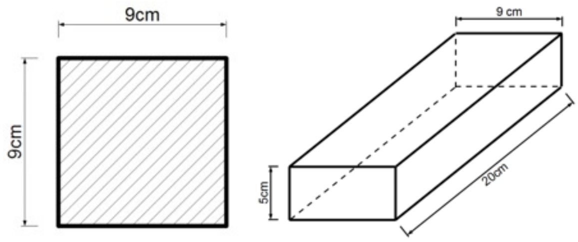

Figure 2: Cross-section of steel members and brick dimensions

Structural Model and Element Types

The beams and the columns of the frame are modelled with the element type 'cbp3', which is a cubic elasto-plastic 3D beam column element (Izzuddin&Elnashai, 1993). Normally 6 or more elements are required per member to capture the spread of plasticity along the member length; however, due to the nature of the problem as described below, the number of elements required here is significantly greater.

The masonry infill is divided into 16 partitions and joined to the surrounding frame through the use of dimensional coupling. Each partition is modelled with a 20-noded 3D brick elements of type 'bk20' (Izzuddin, 2009), and the mortar joining the bricks together is modelled with the 16-noded interface element type 'in16' (Macorini&Izzuddin, 2010). Each brick is modelled using 2 elements with an additional interior interface element, which has different properties to the mortar interface elements, so as to allow possible crack development inside the brick, as shown in Figure 3.

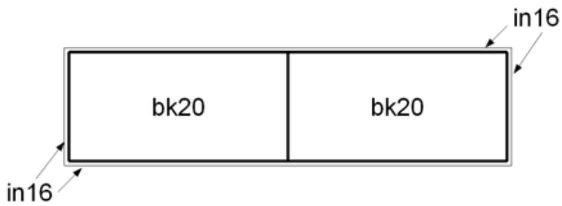

Figure 3: Model for a single brick

Although the interface elements modelling mortar 'in16' (Macorini&Izzuddin, 2010) are shown outside the brick model for clarity, these elements are in fact zero-thickness to start with and coincide with the brick faces on either side. Later, as the analysis progresses, these elements allow the separation between adjoining bricks due to cracks or slip planes developing in the masonry. When these nonlinear interface elements are used, convergence difficulties can arise in static analysis due to the softening characteristics of cracked mortar (Macorini&Izzuddin, 2010). In order to reduce these difficulties and determine the solution up to a significant level of deformation, especially for the case of high normal pressure, a dynamic analysis procedure is utilised (Macorini&Izzuddin, 2010), allowing the sudden release of elastic energy to be balanced by kinetic and viscous energy. This approach is being used in this example as well, where a small constant velocity is applied at the two right hand corner nodes in downward direction leading to a linearly increasing displacement with time.

Partitioning with Dimensional Coupling

The masonry infill is divided into 16 partitions, with 4 different partition sizes, as shown in Figure 4.

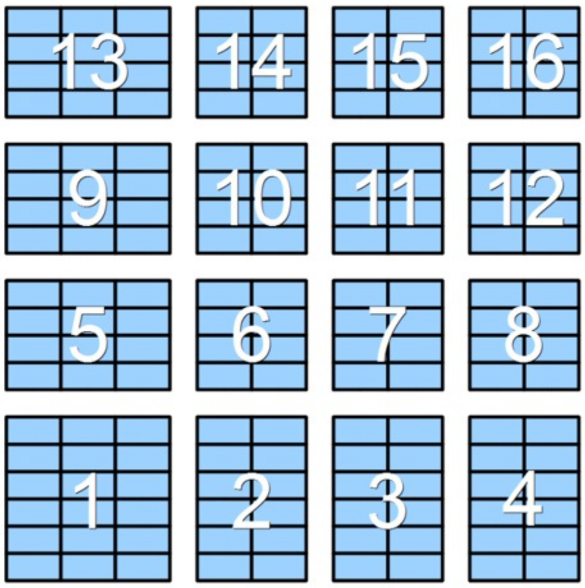

Figure 4: Partitioning of the masonry infill

All 16 partitions of the masonry infill are children to a single higher level partition which in turn is the child to the root partition that contains the frame elements. The intermediate partition, shown in Figure 5, is used to employ dimensional coupling between the frame elements and the masonry infill whilst the partitioned boundaries of the masonry parts are joined without dimensional coupling. For clarity, the locations of the master nodes in Figure 5 are not shown to scale; in reality, these nodes are located along the center line of the frame members.

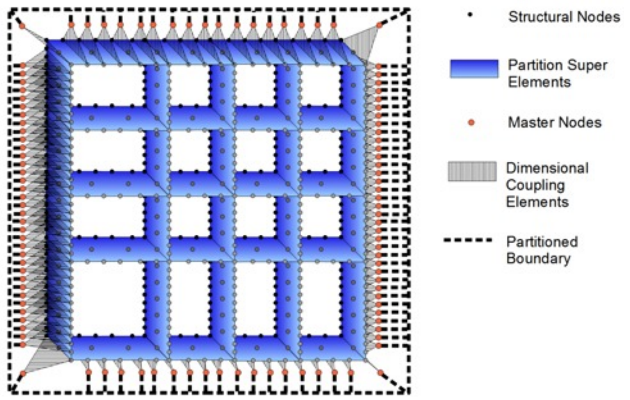

Figure 5: Intermediate partition (level 2) with dimensional coupling

It is noted that the use of an intermediate partition can be avoided by using dimensional coupling between the masonry infill parts as well.The root partition for the current example consists of 1D beam column elements and a single partition super element as shown in Figure 6.

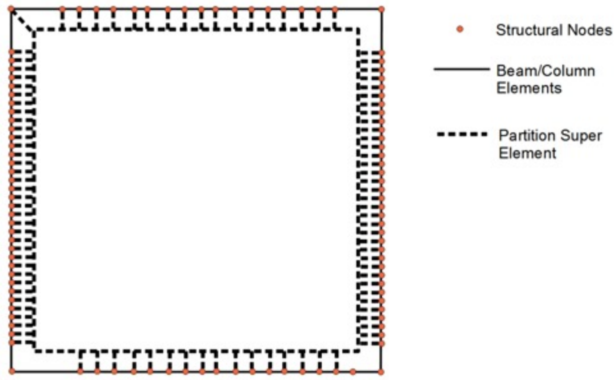

Figure 6: Root partition (level 1)

MATERIALS AND METHODS

Model

The material model used with the brick elements is elastic isotropic with a modulus of elasticity of 2.5×10^5 MPa and a Poisson's ratio of 0.15. The material properties for the mortar and brick interface elements are shown in Table 1, a detailed explanation of which can be found elsewhere (Macorini&Izzuddin, 2010).

RESULTS AND DISCUSSION

All partitions are subjected to an initial load of 19 kN/m^3 as self-weight of the bricks. An initial velocity of 0.05 *m/s* is applied to the free corner nodes (Figure 1)of the parent structure. As a dynamic load, an acceleration of $0.0\ m/s^2$ is applied, which means that the initial velocity remains constant, effectively resulting in a linearly increasing displacement applied to these nodes. The analysis ran for a total of 10,539 loading steps in just about 38 hours, where the final deflected shape at a lateral drift of 0.7 mm is shown in Figure 7.

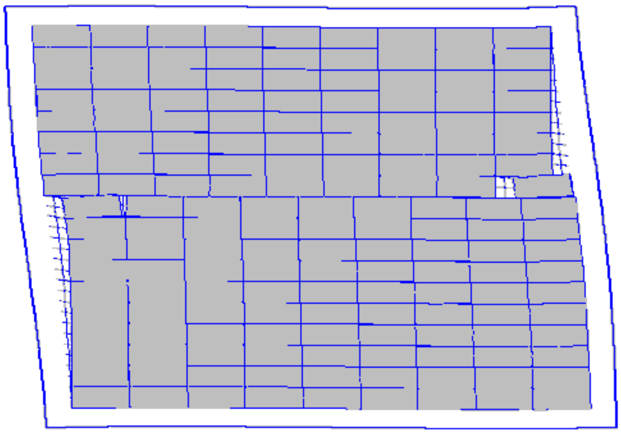

Figure 7: Deflected shape at 0.7 mm lateral drift (displacement scale = 100)

Figure 8shows the plastic work at the interfaces due to the applied lateral drift. Further detailed analysis of the behaviour of this structure is out of the scope of this study. However, the example has illustrated the use of dimensional coupling along with domain partitioning, which has rendered the nonlinear dynamic analysis of such a structure not only practical but computationally feasible.

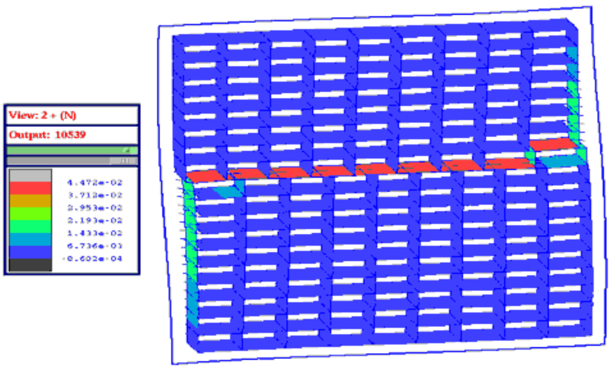

Figure 8: Contours showing plastic work at the interfaces

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