Imperial College London

MIXED-DIMENSIONAL MULTI-SCALE ANALYSIS OF STRUCTURES

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INTRODUCTION

The most accurate modelling approach in nonlinear structural analysis is using 3D finite elements. However, this is prohibitively expensive and typically inapplicable to modelling the overall structural response, where the nonlinear analysis of relatively small structures can require several days of computing time. The present research is concerned with developing a new method for modelling structures under extreme loading, benefitting from the accuracy of 3D finite elements and from the computational efficiency of 1D and 2D elements, through the use of mixed-dimensional multi-scale analysis. Towards this objective, the structure is partitioned into several substructures. Typically, one substructure consists of 1D/2D elements where they are applicable, while other substructures consist of 3D elements (Figure 1) for detailed modelling. One type of problem requiring such detailed modelling is the explicit treatment of bond-slip in reinforced concrete joints. The substructures can also be divided into further partitions leading to an effective hierarchic model.

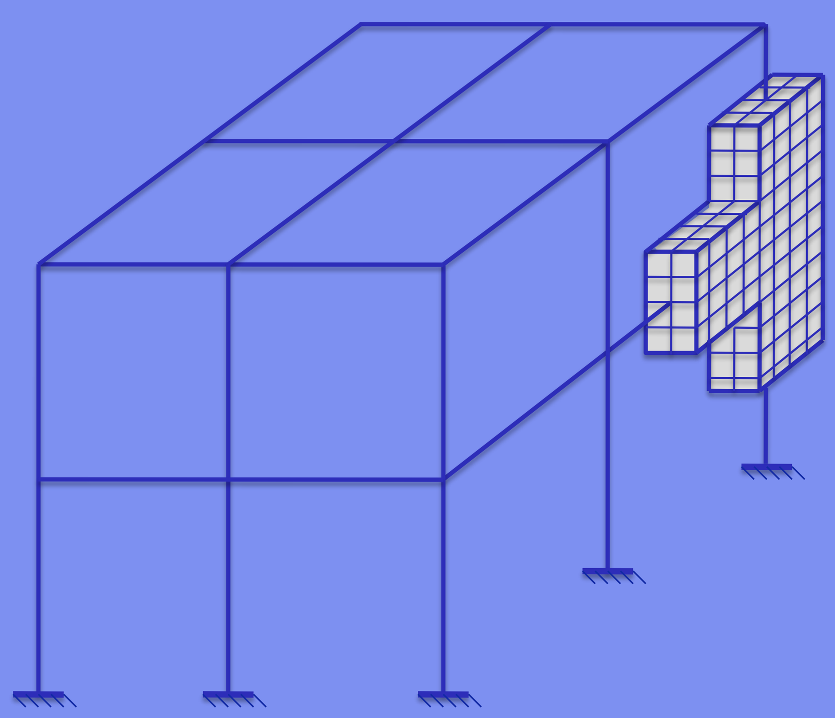


Figure 1: 1D and 3D elements used for various parts of the structure

STRUCTURAL DECOMPOSITION

Mixed-dimensional multi-scale modelling can be achieved by decomposing the system into partitions. This enables parallel computing which can significantly reduce the wall-clock time required for computations as well as simplify the modelling of large and complex structures in comparison with the monolithic approach. A new approach of structural domain partitioning for parallel processing has been developed in this work, where a partition child sub-structure in a parent structure is represented by a dual super-element, with a shadow super-element wrapped around the partition boundary in the child process (Figure 2). This approach, in addition to being hierarchic, offers the possibility of using elements of different dimensions and/or different integration schemes in various partitions. The proposed structural decomposition scheme has been implemented into ADAPTIC using the Message Passing Interface (MPI) Library, enabling parallelisation on multi-processors. One occurrence of ADAPTIC assumes the role of coordinator dealing with the parent structure, while each of the remaining processes deals with a single partition (Figure 3).

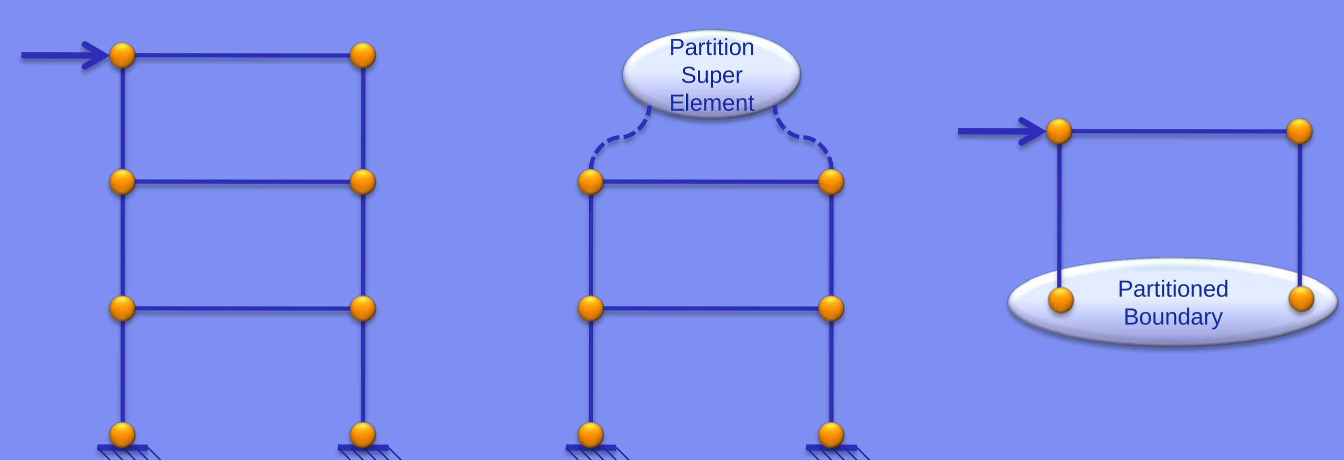


Figure 2: The original structure, parent structure, and partition

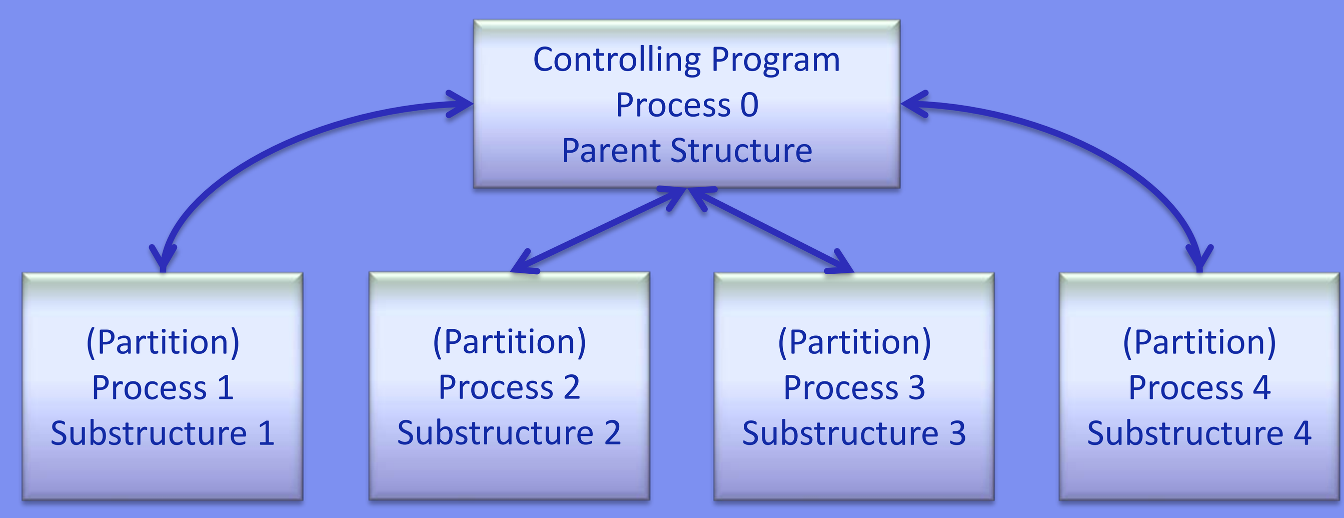


Figure 3: Coordination and communication between controlling program and partition processes

BENEFITS OF PARALLELISATION

Parallelisation of structural analysis typically increases the total computational time owing to the introduction of partition super-elements; however, wall-clock time is expected to significantly diminish as demonstrated by counting the number of multiplication operations required to solve a 4x4 grid of 16 2D elements, assuming 1 DOF per node.

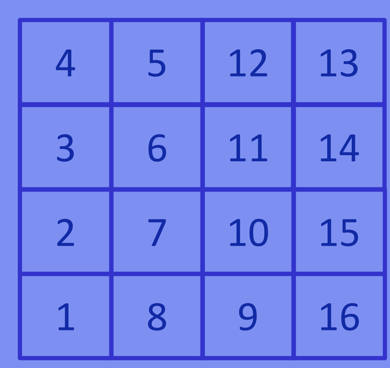


Figure 4: 4x4 grid of 2D elements

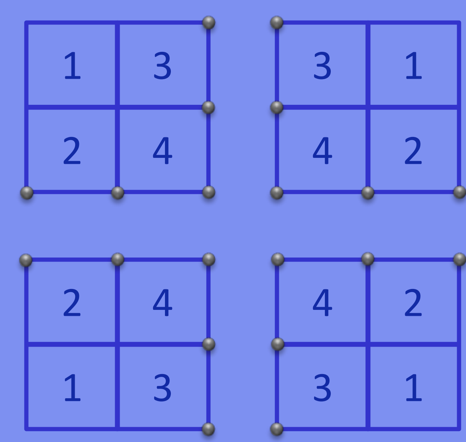


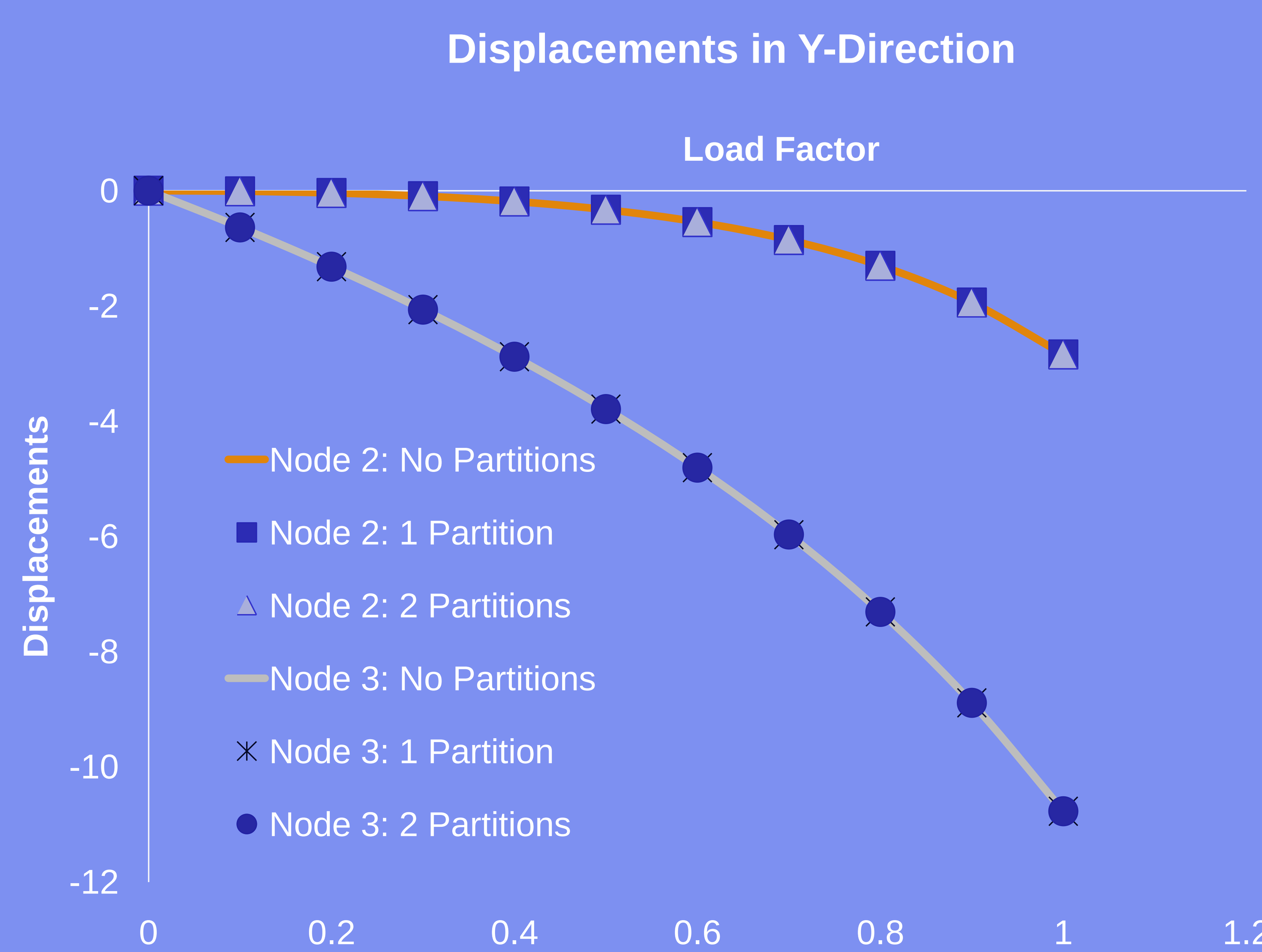
Figure 5: The 4x4 grid as 4 partitions

Monolithic Approach	No. of Multiplication Operations = 664	
Partitioning Approach	At Partition Level = 92 At Global Level = 184	Equivalent Multiplication Operations = 276
Wall-clock time to be saved in this case is 58% (These calculations are performed ignoring the communication overheads)		

Table 1: Comparison of Multiplication Operations required for monolithic and partitioned analysis on 4 processors

VALIDATION

The High Performance Computing (HPC) system of Imperial College is being used for validating the developed structural decomposition approach. Figures 6 shows some of the initial results obtained by analysing Lee's frame with partitioning.



DIMENSIONAL COUPLING

To achieve the objective of mix-dimensional modelling, interface elements are being developed for dimensional coupling between partitions with different types of element. This will be integrated with the developed partitioned approach for parallel processing.