13. CONCLUSIONS AND CONTRIBUTIONS

13.1 A RECAPITULATION

Parallel processing has provided viable solution to many computational intensive numerical problems of science and engineering. Multiprocessor machines, consisting of hundreds to thousands processing elements interconnected and cooperating with each other for solving complex problems, are developed by number of countries. Efforts are still in progress to develop hardware, software, and computational tools for availing better computational power at lower cost. Various research organizations in India are also involved in development of supercomputers for becoming independent in computational resources. These supercomputers are not only costly, but require heavy maintenance and their use need theoretical background of parallel processing, operating system and networking. Generally various research organizations can access these facilities for developing their applications, but not many scientists and engineers can utilize these facilities due to number of complexities. Recent developments in networking, however, has made it possible to utilize network of computers, as available in most of the organizations in the form of LAN, for solving computational intensive problems at very low cost.

The present study was aimed to implement various structural engineering applications over network of computers to make development of distributed application simple. The potential of using WebDedip along with LAN for distributed structural engineering applications was explored in the present work through wide variety of large size problems.

In the beginning, feasibility of WebDedip environment was studied through **static** analysis of **microwave tower**. Substructure technique was used to distribute the computations among various computers and finally the result of entire structure was obtained. After gaining confidence in use of WebDedip, static finite element analysis was implemented over distributed computing environment. Initially, small size problems of beam under pure bending and deep beam were tested using substructure technique. In substructure technique advantage of banded matrices was taken to reduce computational load and communication time. Subsequently, large size problems of a square plate with circular hole subjected to in plane forces (**27980 DOF**), annular plate (**17175 DOF**) and skew plate (**27663 DOF**) subjected to transverse loading were implemented over different number of computers of LAN. The results of analysis were verified with those available in literature and speedup was calculated. Also the effect of ratio of number of internal nodes to interface nodes was studied with one large size problem.

Next, improvement in computational speed in case of **Dynamic** analysis using distributed processing was studied. Natural frequency calculation of rigid jointed two-dimensional frame was implemented over different number of computers. In substructure technique, static and dynamic **condensation** techniques for eliminating internal degrees of freedom were discussed. Speedup was observed when a problem of **300-storied** plane frame with 9933 DOF was implemented over two to five computers.

A time consuming process of training of **artificial neural network** was then implemented over distributed computing environment. For training Counter Propagation learning algorithm was used. An example of design of rectangular **column** subjected to axial load and biaxial bending, requiring tedious manual calculations, was considered. For training **7440** input-output data sets, derived from design aid of IS: 456, were distributed among various number of computers and speedup was observed.

As **internet** is widely used and becoming an important infrastructure facility, its use for distributed application was explored through two applications. In one application software on remote computer was accessed using internet and WebDedip, while in other application finite element method was implemented on two computers connected through internet. Small size problems were taken to illustrate the application.

As the use of biologically inspired **Genetic Algorithm** for optimization of structures is gaining increased applicability, it was implemented over distributed computing environment. As in GA evaluation of unconstrained objective function for a population is time consuming process, it was distributed over different number of computers. The problems of **weight optimization** of plane and space trusses were considered to show feasibility of distributed GA application in WebDedip environment.

Laminated composite materials are used widely for lightweight structures because of their favourable properties. As analysis of laminated composites using higher order shear deformation theory consumes more computational time, it was implemented over different number of computers. A problem of simply supported layered composite plate subjected to sinusoidal loading (**29766 DOF**) was solved using three, four and six computers and speedup was observed in each case.

Finally, **nonlinear analysis** which is quite time consuming process because of its iterative nature was attempted to have advantage of distributed processing. A problem of geometrical nonlinear analysis of clamped plate subjected to uniformly distributed load (**20165 DOF**) was implemented over different number of computers and computational efficiency was observed. For distributed implementation two approaches were used. In first approach the calculation of unbalanced load vector, linear, nonlinear and initial stress stiffness matrices was distributed to different computers. While in other approach the calculation of tangent stiffness matrix and load vector for different substructures was distributed to different computers.

In all applications discussed above, computer programs for different tasks were prepared using **VC++** and configuration of application was done through WebDedip. Most of the applications were implemented over network of Pentium IV computers having 256 MB RAM and running on WINDOWS-XP operating system at 1.8 GHz speed and which were connected through 100 Mbps ethernet network.

13.2 CONCLUSIONS

1. WebDedip environment, which was primarily developed for distributed image processing applications using JAVA technology based on client-server approach, has also been found quite useful in distributed data processing applications.

2. The most attractive feature of WebDedip environment noted here is that it does not require any message passing functions in the program. User has to simply visualize parallel implementation potential of an application and accordingly divide the problem into number of tasks, which can run concurrently on various computers, and communication between tasks can be done through FTP. Thus without having any theoretical background of parallel processing, one can easily process his problem with due advantage of parallel processing.

3. As network of computers is available in most of the organizations, with the help of WebDedip, Local Area Network can be converted into distributed computing resource without any additional cost.

4. Substructure technique is inherently suitable for coarse grain implementation of structural analysis over distributed processing. In the implementation, generation of stiffness matrix and load vector for different substructures can be easily distributed to different computers and after computation of boundary displacements, calculation of internal displacements and element stresses of each substructure can be carried out in parallel without loss of any accuracy in final results.

5. Calculation of substructure stiffness matrix and load vector is quite time consuming. This is due to renumbering of internal and interface nodes for eliminating internal DOF using static condensation. It is clear from different applications that as the ratio of number of internal nodes to interface or boundary nodes increases, time to compute substructure stiffness matrix and load vector increases.

6. The computational efficiency depends on size of problem i.e. total number of unknowns. When distributed processing is implemented for small size problem, communication time gives more overhead to computational time and therefore computational efficiency is not that significant in such cases.

7. As communication between computers is done through File Transfer Protocol, before communication takes place, authentication of computers is required and so communication time does not depend much on size of files to be

transferred. It depends mainly on network traffic. Sometimes due to network collision communication may not take place properly.

8. With the increase in number of computers for solving a problem, the communication time increases and computation time reduces, which finally reduces the speedup and computational efficiency. It is clear from various applications that for better computational efficiency ratio of computational time to communication time must be kept more.

9. For better understanding each substructure must be assigned to one separate computer if sufficient number of computers are available. If number of computers are less than number of substructures, more than one substructure may be assigned to one computer.

10. In distributed implementation on WebDedip static load balancing i.e. distribution of computational load in beginning depending on computational power of computer is very simple. But dynamic load balancing i.e. modification of computational load among various computers during the process is difficult and hence it is not recommended here.

11. For distributed static finite element analysis, computational efficiency of 80 to 90% has been observed with different number of computers.

12. Dynamic analysis of structure for calculation of natural frequency can be implemented as easily as static analysis over distributed computing environment using substructure technique and WebDedip.

13. For the calculation of substructure stiffness and mass matrices either static condensation or dynamic condensation technique can be used. When regular plane frames are divided into more than three substructures static condensation gives natural frequency of first three modes almost similar to that of considering entire structure.

14. For distributed dynamic analysis an efficiency of about 60 - 70% was observed for the problem of 300 storied plane frame.

15. The artificial neural networks exploit the massively parallel local processing and distributed representation properties that are believed to exist in the brain. In the present work CPN was selected over BPN because of its suitability to deal with problems involving thousands of links. The idea was to exploit further its inherent parallelism capabilities of data processing. It has been found quite appropriate for distributed implementation as it does not require inter process communication during training of network using assigned set of input – output patterns.

16. The computational efficiency observed in distributed training of neural networks, for the problem of design of rectangular column varies between 60 - 80% depending on number of computers employed for tackling the problem.

17. Distributed computing has made it possible to use computational resources available on different computers connected through internet. The use of internet for distributed application was clearly demonstrated in the present work with the help of two examples. Using this facility the latest version of expensive software can be easily made available through internet without investing large amount on purchasing / updating the same.

18. As most of the time during the internet usages like reading and writing email, browsing web pages etc. the CPU is idle. The idle CPU time of computers connected through internet can be effectively used for solving computational intensive problems. Volunteer computing and Grid computing are using the same concept.

19. Computational speed of Genetic Algorithm for optimization of structures can be improved using distributed processing. For distributed implementation of GA using WebDedip, the populations can be distributed to various computers for unconstrained objective function evaluation, while genetic operations like reproduction, cross over and mutation for next set of populations can be carried out sequentially on one computer. Working of this concept has been clearly demonstrated in the present work with the help of examples of pin jointed structures.

20. In distributed implementation of GA for weight optimization of relatively small size plane and space truss problems an efficiency of about 40 - 50% was noted. But higher efficiency is expected for larger size problems.

21. Two different alternatives were critically examined in distributed analysis of laminated composite plate using finite element method. In first alternative the calculation of stiffness matrix and load vector for different layers was carried out in parallel on different computers and assembly and solution was carried out sequentially on one computer. While in second alternative substructure technique was used in which stiffness matrix and load vector for each substructure, consisting of number of layers, were calculated in parallel on different computers. For a large size problem having total 29766 unknowns, the first approach is found to demand larger communication time compared to the second approach.

22. For distributed finite element analysis, using higher order shear deformation theory of laminated composite plate using substructure technique and WebDedip environment, computational efficiency of 60 to 80% was observed with different possibilities for the problem considered.

23. Again two different possibilities were explored in FEM based large deflection analysis of plate. In the first investigation calculation of residual force vector, and different stiffness matrices for entire structure was carried out simultaneously on different computers and subsequently assembly of stiffness matrices and solution of equations was carried out sequentially on one computer. In the second investigation substructure technique was used, in which tangent stiffness matrix and load vector for each substructure were evaluated concurrently on different computers and solution for boundary displacements was carried out sequentially on one computer. The first approach has been found suitable for smaller size problems while second approach has been found more suitable for larger size problems. However, combination of both the approaches is recommended here to achieve better computational efficiency for very large size nonlinear problems.

24.The computational efficiency for distributed geometric nonlinear finite element analysis of plate using substructure technique and WebDedip environment was found 60 – 80% for the problem considered.

13.3 CONTRIBUTIONS

1. The WebDedip environment, which was developed originally at Space Application Centre, ISRO (Indian Space Research Organization) Ahmedabad primarily for image processing applications has been tuned in the present work to deal with distributed data processing. It has been shown that using Local Area Network, as available in most of the organizations, and WebDedip environment structural engineer can implement his application over distributed computing environment. Structural engineer without bothering much about technicalities of parallel processing has to simply identify the part of applications, which can run on different computers in parallel and accordingly, divide the application into small tasks. The programs are to be prepared for these tasks, and taking advantage of no message passing functions the configuration of application is to be done using WebDedip.

2. Using Local Area Network and WebDedip environment, a wide variety of applications of structural engineering has been implemented on distributed computing environment. The applications included in the present work covers wide spectrum of structural engineering like analysis of skeletal and continuum structures in static, dynamic, linear and nonlinear domains in addition to problems of laminated composites and optimization.

3. All applications reported here are developed in the most powerful programming environment i.e. Visual C++. Computer programs are developed for each application with a potential to handle large size problems, and applications are configured using WebDedip environment without any special hardware or software, i.e. at no additional cost. The performance of each application under distributed computing environment has been critically examined. In all applications advantage of distributed processing is observed.

4. Application of substructure technique in some of the difficult areas such as dynamic and nonlinear analysis of large size problems has been successfully

demonstrated. For dynamic analysis it is shown that static condensation technique for substructure stiffness and mass matrices is adequate if structure is divided into more than three substructures.

5. Various alternative strategies for development of distributed application using WebDedip have been discussed to give clear idea of different possibilities in structural analysis with a mention of advantages and limitations of each alternative. This may guide the future research work in proper direction.

6. Use of internet technology in structural engineering, which can be next era of computing, has also been successfully illustrated. Using this concept latest version of commercial software can be made available at nominal cost as well as computers connected through internet can volunteer the idle CPU time for computational intensive problems.

7. The advantage of using distributed processing in some of the new areas like training a artificial neural network with 7440 input-output data sets for column design and evaluating objective function when applying genetic algorithm to truss optimization problem has been clearly indicated by computational efficiency details and speedup graphs.

13.4 FUTURE SCOPE

1. In all the applications, computers employed for parallel / distributed data processing were having 256 MB RAM. For large size problems thus more time is spent in swapping the data between main memory (RAM) and secondary memory (Hard disk). In further study the size of RAM may be kept as 1 GB to see its effect on performance.

2. The number of computers considered in this study was limited to six. More number of computers can be employed to solve very large size problems to study speedup and computational efficiency.

3. The network used in this study was the part of LAN, which was accessible to number of users during implementation of some of the applications. This can not give true picture of actual communication time required by the

application. A dedicated network may be employed for distributed processing to have a better picture of performance.

4. In the application of Genetic algorithm, weight / size optimization of pin jointed structures was attempted. WebDedip environment can be further explored to find its suitability in solving GA based configuration and topology optimization problems of such structures which are much more time consuming problems.

5. In analysis of laminated composite plates anisotropic plate theory was used. A three dimensional analysis can be implemented for distributed analysis of laminated composite plates for better representation.

6. Distributed dynamic analysis was implemented for plane frames in this study using direct stiffness approach. Distributed dynamic analysis of continuum structures using finite element method may be thought of for future application.

7. Dynamic and nonlinear finite element analysis of laminated composite plates may be attempted as an extension of present static linear analysis of laminated composite plates

8. Material nonlinearity is another field where distributed processing may be as effective as in problems of geometrical nonlinearity and hence may be explored.

9. Pre-processor may be developed for menu driven input and post-processor for graphical output to make the application more user friendly and attractive.

10. In the present study substructuring technique was used. The use of hierarchical substructuring particularly for very large structures may prove more beneficial.

11. As the Grid computing is an emerging technology for computing using large number of computers connected through network running on any OS, it can be explored for large time consuming problems of structural engineering.