11. CONCLUSIONS AND CONTRIBUTION

11.1 SUMMARY

The present work was focused on the disasters of earthquake, wind, fire, flood, blast and tsunami, which greatly affected the world community recently. Based on the current status of ongoing research in this field, these disasters were studied to identify specific issues and for preparing a software to include interaction in virtual reality.

The dynamic nature of earthquake loads were examined and the performance based approach of **Pushover Analysis** was adapted into a software in VC++ to get results of a Non-Linear Static analysis. The results from the Pushover Analysis were used on a **Virtual Reality** platform in 3DS Max to get the damage and retrofitting solutions.

Cyclone forces were studied and VC++ software prepared for lateral wind loads on short buildings and the dynamic effects on slender structures for **Gust Factor method** and Dynamic Response Factor method. SAP2000 was used to analyse the building for the wind loads on frames with Shear Core, Shear Walls and Bracings. Finally Virtual Reality was implemented on the frames with shear walls and bracings in 3DS Max .

Fire loads and their effects were examined for **Compartment Fire Loads** in two compartments. Comparisons were made for 5 incremental cases of fire load on bottom slab, corner columns, all columns, all beams and top slab for 3 temperature increments of 450°C, 600°C and 1200°C for each compartment.

Structural aspects for Flood control were studied for various solutions and also for construction of **embankments** and **dams** which were examined through case studies of two rivers Sabarmati at Ahmedabd and Tapi at Surat. Design of retaining walls for **earthquake forces** was also undertaken

Blast phenomena and general principles of blast loading were studied and response of structural elements and failure modes were examined. **Progressive collapse** was also studied as it is a common cause of failure in the event of a blast. Structural aspects of **Rehabilitation** for **Tsunami** effects were briefly described along with the special measures required to be taken.

11.2 CONCLUSIONS

1. "Know your enemy before you take him". This is the central paradigm that should be worked on. It is important to know every aspect of a disaster before one tackles the structural aspect. Hence learn about the nature of the force, its demand on a building, the amount and type of damage it can cause; Other factors that might add to its fury, the nature of the building itself; Best practices across the world and at various time periods; The tools that are available and their limitations.

2. Structural aspects of disasters should be conceived and addressed in a holistic manner, taking into account broader aspects of disaster management. In isolation, the best of structural disaster mitigation efforts will prove worthless if a single collaborating aspect is mishandled. Thus structural engineers should learn to work in coordination with other disaster experts for fire, floods, blasts, tsunami etc.

3. Analysis software are powerful carriers of mathematical computations, but lack the prowess of cad software which have the power to deliver the best of graphics. VC++ has an inherent strength of programming in addition to its powerful GUI interface and user friendly windows and menu-driven capabilities. These features of VC++ make it highly conducive to efficient programming which gives an attractive appearance in the front-end for user convenience along with an extremely powerful back-end features for a robust logical program.

4. The finite element capabilities of SAP2000 allow accurate results of the most complex problems. Though window-based, in order to fully exploit the

capabilities, it needs expertise which takes some time to learn the intricacies. The outputs are lengthy and tedious and it is up to the user to sort the relevant parts.

5. Add-on modules created in VC++ can be interfaced with SAP in order to customize an otherwise rigid software.
6. Out of many Virtual Reality implementation platforms such as MATLAB, Maya, AutoCAD and Flash, 3DStudio Max which has been used in current work is found most suitable for its high resolution and professional level capabilities for animation, textures, camera, lighting and rendering.
7. Performance based analysis of structures has been adopted by all international codes. Thus Pushover analysis needs to be incorporated in codes and analysis even though it is system based and tedious to apply and interpret.
8. Programming for Pushover Analysis is complex and the method is limited to the first 2-3 modes of the building. If steel details of a particular joint are not available, the hinge property will be inaccurate and consequently the analysis and results will be far from the actual.
9. Preliminary evaluation of buildings for configuration irregularities like soft storey or plan irregularities must be considered before actual analysis. Torsional effects may be minimized at the outset by proper location of vertical resisting elements against mass distortion. Such buildings should be designed using dynamic analysis. Ductility provisions are most important in such situations. Even if demand-capacity ratios are satisfied, strong column-weak beam check may be dominant, requiring retrofit strategies.
10. Local or global retrofit options need to be judiciously incorporated after damage details have been evaluated. Besides ductile detailing of the new additions, proper anchorage and bonding of new components with the old ones need very careful detailing.
11. Retrofitting of frames to induce ductility by the conventional methods is possible but cumbersome. Addition of shear walls or brace elements may be a suitable alternative to retrofitting of frames to make them more ductile.

Shear walls should be employed for increasing stiffness where necessary and should be uniformly distributed in both principal directions.

12. RCC Jacketing is recommended when significant enhancement of member capacity (axial, shear or flexural) is required. The cost comparison reveals that under the influence of similar parameters, provision of shear wall is more expensive to that of jacketing of columns. But for a perimeter frame, provision of shear wall is definitely more suitable than jacketing of all the columns in case where the number of weak columns is high.

13. Virtual reality (VR) aspect of damage, retrofit and evaluation, is a totally new concept for structural engineering. Program interfacing for virtual reality platform and transfer of output from one module to next needs extensive scripting effort. But scripting gives the edge to 3D worlds which makes data transfer possible from one software to another. Any engineering application needs this interfacing for its successful implementation and evolution.

14. Besides the computer memory, run time which sometimes takes one or two days, is the biggest deterrent for application of VR into mainstream analysis and reports.

15. Implementation of VR into mainstream analysis gives the engineer a chance to take multiple re-runs with as many changes he wants in the structural components, thus making the final output extremely optimized without any loss in real time on the actual site. Besides, the engineer can breathe life into the building by continuous involvement at every level which on a site would otherwise be a near impossible task.

16. Gust Factor (GF) method of IS: 875-(1987) is used in practice for analysis of slender buildings. The method is based on hourly mean wind speed besides other inherent limitations of complex charts. Further the GF method does not take into account wind directionality or area averaging, both of which play an important role in wind engineering. Also the GF method gives somewhat conservative results and is not conducive to programming. Dynamic Response Factor (DRF) method in proposed draft

is found more contemporary and can be programmed too, which ensures its incorporation into building design for wind and cyclone effects.

17. Buildings with ratio of height to shorter dimension greater than 5 are designed as tall buildings. It is important to have shear core to resist the wind lateral force. Besides this, from various options of placing the shear wall and bracing systems for mitigating wind dynamic effects, the position at corners is very effective. Also shear wall systems are effective for resisting the shear but torsional component is resisted effectively by the corner bracings.

18. Proposed draft revision and ATC-60 take into account across-wind effects which are totally missing in current code. Across-wind effects are not negligible and hence cannot be neglected. Torsional effects are also totally missing in both current and proposed revisions. Coastal zones on east and west face severe cyclone storms and yet they are not addressed in the current code. Proposed draft has given an additional factor to include cyclones. This is an important consideration and can make a difference of 1.15 to 1.3 times to the basic wind speed itself.

19. Building frames with shear walls are found to respond better to wind loads as compared to braced frames. Walls on the sides undergo least forces as compared to walls on the corners. While axial and shear forces are borne very well, torsion and bending moments are found quite high even with shear walls or bracings.

20. Virtual reality implementation of wind loads incorporates the storey drift and displacements that the building will face under wind. However it is difficult to demonstrate the response of building under different situations of shear wall and bracing positions, as displacements cannot be distinguished very distinctly.

21. Prescriptive codes have given fire resistance ratings based on ASTM E119 fire exposure and its acceptance criteria since 1920s. The types of inflammable materials and even the compartment contents have changed totally. Though designs based on these codes can withstand fires as they are intended to, they appear to be too conservative.

22. Performance based fire analysis and design are nearer to the actual conditions, but as there are no guidelines or codes in place for fire load calculations, there is confusion as to which is the right approach. Hence a definitive method needs to be evolved for the calculation of fire loads.

23. It is observed that fire loads in inner compartments are more severe than those on the outer edges of a building. Not only are the axial, shear, torsional and bending forces higher but the number of members failing inside as well as outside the compartment is also bigger. This may be attributed to the continuity of members in the inner compartment and the severe torsional effects that the compartment undergoes, thus inducing stresses in all the members connected to the critical member which undergoes the high temperature failure.

24. It is further observed that in both the compartments the critically affected members are diagonally opposite indicating that the compartment as a whole undergoes critical torsional stresses induced due to differential temperature stresses in the members which are affected as per their proximity to the source of fire.

25. Prescriptive codes have recommended only the requisite concrete cover and minimum thickness of member for a particular fire resistance rating. It is important that the codes expand their recommendation to explicit measures of fire proofing critical members, fire walls and rehabilitation of concrete members damaged by fire.

26. Flood control measures are very well defined in the water manuals of all countries. It is upto the authorities to maintain a high level of check, repairs and maintenance, to be prepared for the flood when it finally strikes. As in case of most disasters, immediate and short term measures which are quick and most visible are usually undertaken while the long term measures such as storage reservoirs, additional embankments, channel modifications etc. take a back seat.

27. Across the world there is a debate as to whether embankments should be or should not be constructed along major river banks. There is not enough evidence to show that embankments play a negative role in stopping the

waters from returning back into the river and thus aggravating the situation. The role of the structural engineer becomes crucial here, for embankments as conceived in the flood manuals, do serve a definitive purpose of flood control provided they are judiciously maintained along with sufficient provisions of outlets and de-clogging.

28. Modern trends of earth reinforced panel and geo-grid or soil anchor technology should definitely serve as a cost efficient alternative to the cumbersome and costly RC counterfort retaining walls. It is upto the engineers and the water commissions to build into the manuals enough provisions of maintenance and repair of these structures so that their purpose is fulfilled effectively.
29. Wherever there is a dam serving as a flood control structure, the water levels to be maintained during the monsoon irrespective of the rainfall through the season, should be as per the flood manual. Besides this, the next most important aspect is the guarding of the river bank against encroachment and flood embankments that need constant upkeep.
30. As against the normal loading aspects, blast loads depend on the dynamic properties of the members. Besides this, the blast load itself comprises of overpressure and suction as the shock wave moves towards the target. Thus pressure-time components play an important role in blast resistance.
31. While designing for blasts, progressive collapse needs particular attention. The overall stability of structure will rely on continuity and ductility of the elements to redistribute forces within the structure.
32. Connections need to be designed so as not to fail before their main elements so that the loads can be redistributed in the extreme events of blasts and fires. Thus they become critical components in frames.
33. Site and plan of the structure play a very important part in case of a Tsunami. Also from the structural point of view foundations, walls and all other fixtures should be properly tied down. Foundations in particular should be protected from scouring of soil below. Besides this the critical members such as the ground beam should run around completely so that it

is connected continuously and becomes an integral part of the whole structure.

11.3 CONTRIBUTION

In the backdrop of research on disasters across the world, information dissemination of revisions and guidelines is being done on a very wide scale. Typically, in this information and communication age, even micro level details of disasters and their implications are easily available. This has created a situation where making a choice or coming to a particular decision out of so many available alternatives, becomes more difficult for the engineering community. Present work brings to the fore, certain solutions specific to disasters and the development of a comprehensive software to serve as a tool, besides opening up the new frontier of a virtual world in structural engineering.

1. ***Software for Performance Based Analysis:*** There is a growing need to switch structural engineering practice to performance based design. In the current work, the complex, non-linear and dynamic nature of earthquake was examined for a performance based approach through Pushover Analysis. Programming is done in VC++ to prepare a user-friendly software SA-DVR, for Pushover Analysis of earthquake forces. The complex nature of a dynamic problem coupled with the performance based approach makes programming an extremely challenging task. Following modules have been implemented in SA-DVR: Response Spectrum Analysis, Iterations for a displacement driven increment of Pushover, Hinge Locations and Hinge Properties, Capacity Spectrum and Performance Index.
2. ***Aseismic Design Solutions:*** The program evaluates the existing elements for their seismic capacity as well as designing new ones to behave aseismically. Once deficiencies are identified, damage recovery is done through various retrofitting options of either increasing stiffness through new members or strengthening the existing ones.
3. ***Software for Cyclone Loads:*** VC++ software is prepared for the static equivalent lateral wind loads on short buildings. Dynamic effects of wind on a slender structure are also included both for *Gust Factor method (GF)* of

IS:875 (1987) and *Dynamic Response Factor (DRF)* method proposed in draft revision of IS:875 in the software. *Virtual Reality* has been implemented by creating frames with shear walls and bracings in 3DS Max along with the displacements. Thus all the three aspects of analysis, retrofit and preventive measures for wind have been automated and put on a virtual platform.

4. ***Fire Loads:*** In existing literature fire has been studied for its effects only in isolation on individual members. A performance based approach for fire loads on the structure as a whole has been put forth and fire loads and their effects have been examined. This disaster has mainly been in the domain of fire protection engineers with very few structural engineering aspects. As no formal guidelines for evaluation of fire loads and capacity of structural elements are in place, recommendations on the same, based on computer implementation of compartment fire results, have been given.

5. ***Recommendations for Prevention and Mitigation of Disasters:*** Solutions for all disasters incorporated in present work, are open ended. The common theme of performance based approach for each hazard can effectively prevent it from turning into a disaster. It is not possible to design any building to resist all disasters but its performance limit can definitely be designed. Weak links for force dissipation should be built into the system; Progressive collapse can be forestalled by rehabilitating critical members; Torsional aspects can very well be removed by regulating mass and stiffness eccentricities for earthquake, wind, fire and blast. Flood control and Tsunami aspects call for judicious land planning and monitoring. Structures such as embankments, levees and check dams prove to be effective solutions, if provided in small measures under strict control and monitoring mechanism as per the relevant water manuals and tsunami guidelines.

6. ***A Comprehensive Software:*** Of the various platforms tested for their strength in programming, modeling, analysis, design and 3D animation and web-enabling, VC++ was selected for load evaluation and analysis. SAP2000 for complex and higher order analysis, 3DS Max for 3 dimensional implementation and virtual reality implications and Cortona VRML was selected for virtual reality and web enabling. An interfacing of

VC++, SAP2000 and 3DS Max, is recommended as a highly efficient combination for structural engineering programming.

Work presented here implements disaster control through software which deals comprehensively with the aspects of evaluation, analysis, design and performance based review, all built into one as follows:.

- Evaluation of forces (both static and dynamic) with options of the relevant Indian code or standard international guidelines such as FEMA, ATC, BIS.
- Response of building and its capacity against the demand.
- Types of damages and visualizing the effect on the virtual building instead of presuming from charts and tables.
- Prevention and mitigation aspects for the particular disaster.
- Retrofitting alternatives.

7. ***Programming for Virtual Reality:*** The output and visual animations in the post processor are the only two indicators for an engineer to accept a design solution or go for a revision with a changed parameter. Virtual reality platform provides an invaluable opportunity as an add-on module to computer analysis software which generally need a high level of decision and understanding of the structure even prior to modeling it on the desktop. A paradigm shift has been achieved in work presented here through the introduction of virtual reality into the software.

   The post processor is a virtual world where the user can pan, zoom, rotate; fly, walk or study for any parameter of interest. Before entering into the virtual world, one can choose to avail the structural option to observe the response to a particular loading condition. The VR module includes options of creating geometry, displaying loads and displacements, ductile detailing and finally the damage caused and its retrofit. Hence user, sitting on a PC, can take as many re-runs to check the different parameters, thus optimizing the solution and saving the prohibitive cost of retakes during actual construction.

8. ***Interfacing with VRML:*** The concept of VR has been further widened by implementing the virtual world on a VRML platform thus making it web-

enabled. The user can collaborate with input and fresh ideas from a closed group around the world. Offline too VRML tool gives the option to the user to fly and get to any point on the model created. Physically on an actual site, this would be an extremely tiresome process and impossible to achieve.

11.4 FUTURE SCOPE

- The software prepared can be extended into AutoCAD to get working level drawings.
- Programming for blast, flood and other disasters such as landslides, hurricanes, storm surges etc can be included.
- Interfacing of SAP 2000, VC++ and 3DS Max is an IT job, and it is near impossible to establish two-way traffic of transferring data from main program to 3DS Max and back. At present scripting has been resorted to for this purpose. But interfacing through JAVA needs to be examined and implemented with a multidisciplinary team.
- Once JAVA interfacing is established, the interactivity on the VR platform, can be increased to include all the parameters influencing the building response, so that the engineer can design his structure in the virtual world and see the instantaneous response to the particular disaster.
- This non-immersed VR can further be extended into an immersed one where the user would wear a head gear and gloves to guide his movements in the virtual world and where he can actually feel the pull and push and other such impulses through the resistance offered by structures. This would need a full laboratory set-up of HMD, haptic devices and sound generators of the CAVE type, connected to the PC.
- In present work, real life failure patterns have been simulated at locations where failure is indicated. Exact simulation of propagation of cracks, which needs complex computations can be taken up as a challenge.
- For projects of high importance, it is desirable to include interference and across wind effects by getting experimental results from turbulent wind tunnel tests on full scale models.

- Complex behaviour of mode shapes of higher order for a dynamic load on the building, and such other complex principles can be very well demonstrated in classrooms using desktop VR. Thus educational applications should be explored in depth.
- Currently response of structure is first calculated and then displayed on VR. The possibility of reversing the process to get the final results should be explored such that, if the user pulls a member to a certain displacement, the output file should be generated to give the forces generated.
- The software can be web-enabled as an Opensource ware, so that, like its other counterparts, it gets automatically updated by users across the world for any new aspect of a disaster or its implications