An Automatic Finite Element Analysis Post-Processor to Detect Regional Overall-time Extreme Condition of Dams

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Abstract. Post-processing is a key task in finite element analysis (FEA), particularly when dam engineering problem is analyzed, whose model is always multi-physics coupled, multi-incremental and element-altering. Commercial FEA software packages can provide powerful solvers, but the performance of their post-processing module is always function-limited and inefficient for engineers. This paper introduces design and implementation of an automatic FEA post-processor for dam engineering, and focuses on how to detect the overall-time extreme physics status of different regions of the dam. Python-based modules are developed in Tecplot to speed up and ease the procedure. The post-processor is tested in a case of dam construction analysis.

1. Introduction
The finite element method[1] is widely used to simulate complex structures and mechanical systems because it provides a powerful tool for the numerical modeling of physical problems. Generally, a complete FEA course should include three main steps in sequence, namely, pre-processing, calculating, and post-processing[2, 3]. The objective of post-processing is to make FEA results accessible and understandable for end users, which can be defined as the “art of result representation.”

Dam plays a key role in modern hydraulic and civil engineering. The FEA of dams is always very complex[4], and involves some characters, such as multi-physics coupled (thermal-structural-coupled[5]), multi-incremental (long-term analysis[6]) and model-changing (during construction stage[7]), making the post-processing of the FEA result difficult and time-consuming. One key purpose of dam analysis is to know the extreme condition over the analysis period, by which we can diagnose whether the dam safety can be ensured, especially some key areas of the dam. Thus, an approach that enables automatic post-processing to detect overall-time extreme condition is proposed in this study.
2. Concept and design methods
The main design principle of our work is being automatically, extensively and user-friendly. In this study, a data extraction and re-organizing program was developed with Python, which can handle data from results of commercial FEA software into Tecplot, and multi-functional Python-based modules are developed for fast, automatic, and efficient post-processing. The programming flowchart of the approach is shown in Fig. 1, and the details of some key problems are presented as follows.

2.1. Group establishment
Elements or nodes can be selected and stored into groups in some FEA software packages. Such groups are called “GROUP” in Adina or “SET” in MSC.Marc and Simulia.Abaqus. The set definitions are important in FEA analysis of dams, by which we can view or mask certain part of the dam.

![Flow chart of main procedure](image-url)
conveniently and assign the material properties. For appropriate and flexible post-processing, the set definitions in the FEA Software should be succeeded.

A naming rule is set in this study prior to method description. The rule indicates that “set” is the set name in the original result file, and “group” denotes the groups used in Tecplot. We regarded group information as numeric variables, such as temperature or coordinates. A group map is introduced to classify different groups, which can be understood as a rule category that assigns the values for existing set names. Frequently, more than one group category, e.g., materials, layers, or location regions, may be necessary. Thus, the array is designed as 2D and is written as follows:

\[
\text{GroupMap}[i][j]=k
\]

where \(i\) is the category number, \(j\) is the set number, and \(k\) is the group value of set \(j\) for category \(i\).

A group map allows for easy decoding and convenient succession of group information as illustrated in Fig. 2. The developed program reads through the result file to search for the “set definition”. A flexible sheet is then generated for users to establish a group map. Users can add or delete group categories. Each category is considered a variable type in the confirmed group map. The program re-reads the result file and detects the element lists of each original set. Finally, the group numbers of different categories are assigned to each element in the list as new variable values. The process is implanted as sub-procedure 3 in Fig. 1.

Figure 2. Flow of group establishment
2.2. Death/birth of elements
Elements are activated or deactivated in some increments in model-changing FEA cases, such as building analysis during the construction stage. Deactivated elements should be excluded to compress the size of output data. In this study, a renumbering method is applied, and a binary array, act[], is used to store the activated/deactivated status of the elements. At increment i, n_i activated elements exist and only these elements are outputted to the Tecplot file. In most FEA result formats, data are stored according to the order of element numbers. During reading, the elements that are not stored or have no result are classified as act=0, whereas all the activated elements are classified as act=1. Lastly, the results of all the activated elements are outputted. The entire process is implanted as sub-procedure ③ in Fig. 1. A typical eight-element example is presented in Fig. 3.

2.3. Automatic contour plotting
A module (as sub-procedure ⑥ in Fig.1) is developed in this study to plot the contour maps through all increments automatically; an image-series video consisting of all maps will also be generated simultaneously. The minimum/maximum ranges of the variable magnitude can be detected and utilized to set the contour level. Conventional repeated and time-consuming manual operation can be perfectly replaced by the module.

![Figure 3. Renumbering method, eight triangle elements example](image-url)
2.4. Extraction of regional extreme values
For dam analysis, the maximum/minimum value in certain parts is very important. This can be performed by sorting the values that belong to a group or locate between two coordinates. A module (as sub-procedure ⑤,⑨ in Fig. 1) is developed to accomplish this function. The module provides users an interface to determine the up/down limits of a certain variable, which can be a group variable or a coordinate variable (X, Y, Z). All the values of the other variables that meet the requirement are then extracted and appended as a row into an allocatable 2D array (Array[][]), which stores different variables in different columns. Lastly, the output values are sorted, and a report of the extreme values of different variables is generated. The entire flow process is illustrated in Fig. 4.

3. Application and results
A thermal–structural coupled analysis of dam construction was calculated to validate the feasibility of the proposed programs and modules. The analysis has more than 105 elements and lasts for thousands of increments, with a result size of almost 100 GB. The methods introduced in this paper successfully converted and compressed the result file into Tecplot. Through the developed module-set, automatic post-processing was implemented efficiently.

3.1. Case description
A high arch dam located in Southwest China was modeled and simulated in MSC.Marc. The construction phase was calculated by considering thermal and structural coupling, and the casting process of the concrete was simulated by deactivating/reactivating elements. The mathematical theory and FE implementation can be found in our previous studies[8-10]. The details of this case are provided in Table 1.

| Number of elements | Number of nodes | Number of increments | Element type          |
|--------------------|-----------------|----------------------|-----------------------|
| 133 340            | 166 033         | 1661                 | 8-node isoparametric brick |

3.2. Results and discussions
Fig. 5 shows the auto-plotting process of maximum principal stress contour maps of the dam body during the construction phase. It can be seen that the dam gradually grows with time. Fig. 6 presents the overall-time maximum vertical displacements contour map, and the upper and lower ranges of
displacements at different heights of the dam are also extracted. Some conclusions can be drawn as follows:

a) Maximum principal stress is a key factor of concrete, which should be controlled not exceeding the permissible standard, otherwise the concrete will crack. From the contour maps, we can see that the maximum stress condition during the construction phase is smaller than the permissible tensile stress standard (2.0 MPa), demonstrating the safety condition of the dam.

b) Displacement is also an important indicator of the dam condition. It can be seen that the displacement along the flow direction, Y-directional, is larger than the other two directions. This is induced by the reservoir-filling process, the water upstream pushes the dam inclining towards downstream. And due to the fixing effect of the dam base, the deformation of the upper part is larger than that of the lower part.

c) By the gravity effect of the upper concrete, we can see that the lower part of the dam settled down. And the center part settled down most because of the shape of the arch dam.

d) The deformation range along the cross-river-direction is almost balanced, in other words, the upper limit and the lower limit is symmetry. This is also a result of the reservoir-filling process, that the water pressure making the dam deform towards the rocks at both banks.
(b) Integration of contour maps

Figure 5. Auto-plotting of contour maps of maximum principal stress
4. Conclusions

With the rapid development of computational technology, the scale of FEA continues to evolve increasingly large. The post-processing of enormous results has become a key issue. Analyzing colossal results through traditional repeated manual methods turns out extremely difficult and time-consuming.

An efficient approach for the post-processing of large FEA results generated by commercial software packages was proposed in this study. Data can be extracted by flexibly handling increments,
variables, elements and groups. Data were also re-organized by considering overall-time extreme value extraction. Multi-functional Python-based modules were developed for fast, automatic, and efficient post-processing. The regional extreme values of different parts of the model are able to be easily obtained.

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