Teaching Structural Behavior through an Interactive and Complete Learning Environment

by

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Submitted to the Department of Civil and Environmental Engineering
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ABSTRACT

Currently, the education of Structural Engineering tends to emphasize, too heavily, the role of structural analysis. Within this thesis, an alternative approach is offered to encourage an intuitive understanding of how structures physically deform, through qualitative and practical representation. The initial stages of development for a web-based integrated learning environment to teach structural behavior to undergraduate engineers are presented. The environment aims to be highly visual and unified, merging text, images, interactive Java simulations and audio.

To ensure the correct approach is being adopted, a literature review on current criticisms and desired qualities of Structural Engineering Education and the theoretical pedagogical issues for learning was carried out. The findings were considered during the design of the environment and its architecture, as presented here with examples illustrating various features.

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BIOGRAPHICAL NOTE

Graduating from the University of Queensland, Australia with a Bachelor of Engineering (Civil) in December 1993, the author received the Arup Engineering Award from Ove Arup and Partners, Australia and commenced working in their Brisbane office as a Structural Design Engineer.

Two and a half years were spent there, enjoying a wide variety of experience and responsibility that challenged and extended her design skills. Detailed design on large-scale projects including the Hong Kong Central Station, Cairns Convention Centre, and major residential and commercial developments were completed. Opportunities were also taken to work in other offices; representing the firm on site for the Cairns Convention Centre and working in the Arup Facades section of the Sydney office.

The author's ties with the building industry still continue during her time at MIT, allowing her interest in structures to be encouraged and a practical perspective maintained. During December/January 1997, further design experience was acquired at the New York office of Ove Arup and Partners.

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Chapter 1.

INTRODUCTION

Strong concern has been raised, internationally, by professional engineers that the level of education of structural behavior is insufficient. As the computer's role continues to become increasingly pervasive in the structural engineer's office, the risk of this problem will only be heightened. The current availability of inexpensive personal computers and powerful software now allows computers to be utilized by structural engineers for the majority of their analysis and design calculations. This is reaching such an extent, that it is now possible to use a combination of software packages to completely design a structural system – though probably a mundane one – on the computer without ever performing a manual calculation.

Fortunately, the apprehension towards this opportunity allowed by technology is being recognized by many. Major problems could be created if the person using the computer does not interact appropriately with the program to ensure the structure will perform its final function as intended. This responsibility of the user depends on their ability to go beyond just analysis to truly understand structural behavior and its implications. Hence, the fact remains that there is no substitute for human engineering knowledge and experience, and the need for it to be concentrated on in an undergraduate's engineering education is acknowledged. This has resulted in the emergence of a new paradigm in Structural Engineering Education, emphasizing the teaching of behavior over analysis.

As an attempt to advocate this new paradigm, the development of an environment with the working name *Momentous* has commenced. The effort is still in its initial stages; however, its goal is to create an integrated learning experience that will enhance an undergraduate student's ability to learn about structural behavior. The approach utilizes images and references in a "virtual library" and exercises made from Java applets in an effort to instill a qualitative and practical understanding of how structures perform. The computer-oriented component will be developed in parallel with a textbook to ensure a fully united and complementary environment.

Having cautioned on the effects of the Computers' predominance in the Structural Engineering Industry and life in general, it is rather ironic that it is the computer that shall provide the teaching tool to encourage in the user a mentality independent of it. What do computers offer that can't be found through alternative means? The simple answer is ease and cost effectiveness. With strong dynamic figures or simulators, concepts and ideas can be conveyed instantly. Previous means for achieving the same result would have included large expensive laboratories, etc. The reader may defend these old style experiments for their physical and practical experience; however, the same is anticipated of a well developed computer package if pertinent images and practical examples are included to provide context to the simulation. Such an approach allows access to so many more users, with the convenience of continual access and repeatability.

The program's ease of use and visual interest is essential to ensure the user stays with the computer and program to continue learning. Acknowledging this should provide *Momentous* with an edge over the various other computer simulators and teaching tools already available on the market. Unfortunately, the author feels many of these previous packages lacked two important factors – a well-annotated, attractive interface and correct emphasis on behavior. The poor interfaces could well be attributed to the available technology at the time of the simulators' creation. *Momentous* is envisaged as going beyond just being a simulator. Emphasis shall be placed on effectively integrating its simulators with strong images, text and examples to provide a more complete environment with context and practicality. The product should be more than the sum of its parts.

To establish an effective learning environment, consulting with the experts was recognized as being essential. Hence, Chapters 2 through to 4 provide these findings. Chapter 2 argues further for the need of more emphasis on Structural Behavior when teaching with the support of observations from Engineering and Teaching Professionals. Various opinions and approaches are presented, including the desired qualities of a Structural Engineer and recommendations to be applied in the development of *Momentous*.

Recognizing teaching as not necessarily the forte of many Engineering Academics and having justified the need for such an environment as *Momentous*, Chapter 3 proceeds to discuss the pedagogical requirements of any learning environment, as set down by Education theory and specialists. Chapter 4 then presents a few of the concerns involved when incorporating technology and computers into education. Many informative design issues are mentioned for implementation in the program *Momentous*.

Finally, in Chapters 5 and 6, the product begins to be built. The design architecture for *Momentous*, presented in Chapter 5, incorporates the requirements and recommendations learnt from the earlier chapters to establish explicit guidelines to work within. Chapter 6 provides details on issues encountered through creating various components of *Momentous* – covering a discussion on the curriculum material to be included, highlighting the difficulties discovered and of course, developing worked examples.

Chapter 2.

THE PROFESSIONALS' OPINIONS ON TEACHING STRUCTURAL ENGINEERING

2.1 Introduction

The necessary desire to imbibe our students with a Structural Engineering experience and intuition, during the educational process, has been introduced to the reader in Chapter 1. How is this knowledge transferred? Providing great emphasis on structural analysis by crunching numbers and assessing results has been to date the most common method, though definitely not the most effective. With this in mind, it is perhaps now appropriate to provide a definition of structural analysis to enable an understanding of its role in Structural Engineering:

> From Wright [23], structural analysis is "the process by which the structure and its environment are modeled to predict structural response."

From this, both the difference and link between analysis and behavior can be seen. Teaching the structural analysis methods utilized by computer programs and for hand calculations, often places much detail and weight on the mathematics and equation manipulation and forgets about the response being predicted. Unfortunately, therefore, the students tend to learn these techniques having hardly ever considered how structures actually physically behave under given loading conditions.

Other responsibilities and tools must also be learnt about structures by the budding engineer; from selecting the appropriate technique to model a structure and its environment, interpreting the analytical results for assessment of the behavior of the actual structure, to making decisions about the design, construction or use of the structure. Generally, there is little challenge and, hence stimulation, for the structural engineer in correctly manipulating an analytical model, especially with the current power of computers, yet it is the manipulation that is often the primary focus of Structural Engineering courses.

Before the author introduces the integrated learning environment, *Momentous*, and its alternative approach, a review shall be provided of recently published opinions of both educators and practicing engineers on the state of education for structural engineers. A range of views was encountered. Fortunately the strongest calls have been encouraging a new paradigm of placing a strong emphasis on teaching structural behavior, with only a few educators still caught in the traditional approach, heavily depending on the many analysis methods for course material. Within this chapter, the review will cover these recommendations though it will not dwell long on the later opinions, instead focusing more on the approaches and advice for teaching structural behavior cited by the various authors, as noted.

Although it appears that the computer is being cursed for its degeneration of a student's practical understanding of structures, it is well acknowledged that it is the computer's increasing and ultimately dominant role in analysis, design and drafting that is forcing a new exciting paradigm. Computer technology provides enormous and worthwhile potential in engineering education, though in doing so it demands radically new approaches. Brohn [7] recognizes this citing the possibility that "a future review of the teaching of structural analysis might reveal that the student's detailed knowledge of the stiffness method is about as useful to a structural engineer as the ability to shoe horses to a modern driver". How does an engineer survive, though, without an understanding of the numerical analysis of structures? It is the role of this and future research to try to work out how to answer this question or at least find the appropriate compromise.

A paradigm shift causes major modification in not just an isolated area, hence, in this case the state of the complete structural course curriculum is also encountering a call for change. Therefore, some discussion on this within this chapter cannot be avoided.

2.2 Judging the New Structural Engineers

When making the harsh claims on the current level of structural understanding of the graduating engineers, what criteria has been used to assess them? Most of the claims have been based on general observations by professional engineers, however a formulated criteria was established by Morreau [15] into the following assessment measures:

1. How successfully do the graduates model the structure prior to analysis?
2. How successfully do they interpret the results of the analysis? Do they recognize the errors in these results? and
3. How successfully do they use the analysis to modify the structure?

Apparently, students generally cope with the first measure quite effectively, especially when posed with a straightforward problem, i.e. when the whole framework can be modeled on the computer. Their inadequacies begin to show in all these measures, however, when the problem needs to be broken down or when boundary conditions are not obvious – essentially, when the engineer really needs to understand how a structure is working.

At a more rudimentary level, Brohn observed in students a poor ability to just sketch the approximate bending moment, shear force, reactions and deflection solution to a structure. He came to the reasonable conclusion of equating these inabilities with a lack of understanding of structural behavior. Whilst, after a review of typical subject matter in analysis and design courses in the United States, Bjorhovde [4] complained that a graduating student too often had a limited practical appreciation of design and engineering. He questioned if their education covered too much theory, or were the students instead being trained to become handbook engineers, without a solid training in the engineering principles.

2.3 Knowing the Ingredients

If one, after this evidence of inadequacy, still has to ask the question why we would desire the abilities of practical thought and structural understanding in our structural engineers, Morreau introduces a wonderful analogy between a good cook and a successful structural engineer to help put the case across.

The need for an engineer to have a strong understanding of structural behavior is like a chef knowing the nature of his ingredients – anyone can follow a recipe, just as a capable engineer can apply a formula, follow a Code or use a program. To create a new dish, or take a short cut, however, requires an understanding of how the ingredients behave in cooking. Similarly, when designing structures, to be able to innovate, refine, approximate, or just know where one is going cries out for a level of understanding structural behavior that we are aiming at teaching.

2.4 The Desired Qualities of a Structural Engineer

The conclusive argument, therefore, is that if there is a problem seen in the product – the graduating structural engineer - then there must be something wrong with the process - the education system. The solution is seen as less emphasis on analysis and more on behavior and understanding. With this established, an outline of the desired abilities has been prepared in Table 2.1. Many of these skills have been collected from Morreau's and Fleming's calls for a change in teaching methods [15, 10]. Predicting does not imply rigorous calculations, but instead expects the student to find only approximate values.

Ideally, the strength of the understanding to be imparted through the goals of Table 2.1 will be to the level of instinct. This list of goals is broad and demanding, though if met will provide the powerful and necessary abilities of a structural engineer. It is the challenge of this thesis to select an appropriate portion of them and commence developing a worthy educational program.

Table 2. 1 The Goals for achieving a Good Understanding of Structural Behavior

Ideal Abilities:

1. ascertain whether a computer model is correct; examining output, questioning if the results are sensible and assessing where modifications could or should be made,
2. understand and predict the effects of changes to a model,
3. ensure that the correct models and approaches for structural analysis and design were chosen,
4. allow back of the envelope calculations for preliminary scheme designs, and
5. achieve some independence from the computer!

The skills required to achieve these abilities:

- differentiating between a structure and a mechanism, applying the requirements of both equilibrium and stability,
- achieving a conceptual knowledge of geometric compatibility,
- following and identifying load paths,
- identifying the various modes (tension, compression, bending, shear) by which the load is carried,
- predicting not just the deflected shape, but actually thoughtfully considering how the structure – be it beam, truss or frame – deforms under load,
- predicting the bending moment and shear force diagrams,
- predicting reactions for any type of statically determinate structure,
- establishing the member forces for a statically determinate truss
- developing and using influence lines for reactions, shear force, bending moment and truss member forces, and
- finally, communicating this information through sketches.

2.5 Analysis Methods and their Inclusion in the Course Curriculum

One of the major dilemmas when preparing the curriculum for Structural Engineering students appears to be obtaining the correct balance in teaching analysis techniques. Brohn, as has been previously mentioned, indicated that a detailed knowledge of the stiffness method might soon be outdated. Please note he does not state that teaching it should be stopped, he just questions to what depth. The author does not fully agree with Brohn, seeing this method as one of the most important of all the methods to be taught. Understanding it in detail, however, doesn't necessarily imply the student will have great insight into structural behavior.

Many of the other available analysis techniques have also been acknowledged by educators as outdated, held onto only by tradition. Fleming, for example, questioned the worth of teaching moment distribution, seeing its main application during the sitting of the Professional Engineering Examination. Perhaps it is time for them to catch up with modern methods as Fleming, also, commented that the type of analysis problems in this exam have not changed significantly over the past 20 to 30 years!

The list of other methods eliminated by Fleming is long: Funicular Polygons, Maxwell diagrams, Williot-Mohr Diagrams, Elastic Centers, the Portal and Cantilever Methods and the Column Analogy. He sees their exclusion due mainly to the software now available. Nevertheless, to throw out all these methods? We do feel some of this is a little rash. After all, the Portal and Cantilever Methods can both be useful tools for checking computer models and during conceptual design. Similarly, Funicular Polygons have been used extensively in Zalewski's new textbook [24], as he provides a good argument for their application in scheme design and development and structural understanding.

Perhaps this evidence points towards not so much the elimination of all these methods just a change in their sequence in the education process. The author proposes that after providing a strong foundation in the basic principles of structures through a course based heavily on behavior, the student could then be introduced to a couple of more detailed analysis based courses such as "Computer Based Structural Analysis" and "Methods for Conceptual Design and Development". The first class could provide more detailed learning of the matrix methods of stiffness and flexibility and possibly finite elements. An additional benefit of this approach is that the student will have a much stronger insight and understanding of the behavior of structures. More material than may usually be expected of an undergraduate may therefore be covered, with the new possible areas including nonlinearity, dynamics and/or control. From the class, a student would then have a stronger background of the methods used in today's structural analysis computer packages and be more astute to their limitations, etc.

The second class on conceptual design could cover a variety of the other analysis techniques; e.g., the Portal, Cantilever and Funicular Polygon methods would seem a good selection. Ideally, the class would be very practical, teaching the appropriateness, benefits and limitations of each of the chosen methods and then allowing the students to apply them in realistic design situations.

The discussion provided in the next section should provide a good corroboration for the aforementioned possible solutions to the position of analysis in the education of Structural Engineering, proving them potentially very worthwhile.

2.6 Suggested Approaches to Teaching from Literature

Naturally, there are as many approaches to implementing the teaching requirements of Structural Engineering, as there are teachers. Within this section, the methods of a few writers from the literature review shall be discussed as they provide important considerations and ideas for the development of both the total course curriculum and *Momentous*.

Each writer had a major theme; Brohn's was a call for a strong graphical and qualitative approach to education, Bjorhovde's interests lay in integrating classes more, incorporating for instance analysis and design at an earlier stage, while finally, Beaufait [2] emphasized the teaching of only approximate methods. As mentioned, each of these approaches is hoped to provide a positive influence on the creation of *Momentous*.

2.6.1 Developing a Student's Graphical and Qualitative Skills

Brohn's major concern in education was an over emphasis of numerical methods at the expense of a real understanding of structural principles. Acknowledged, however, was the fact that as the use of computers increases, so in turn the reliance on calculation as the method of understanding will decrease. To develop his approach, Brohn introduced an interesting model of the brain as a guide in teaching emphasis. Due to its worthwhile insight, the model shall be elaborated on further here.

Through exposure to students from both Hong Kong and England, Brohn was able to test their understanding of structural behavior. From these observations, it was noted that the Chinese students performed considerably better than the English did. The possible explanation given was that due to the Chinese's need to recognize 3000 ideograms, their ability to communicate using graphic symbols must be superior to someone's corresponding skills in the West. Here is where the link with the characteristics of the left and right hemispheres of the brain is introduced. The Chinese students' superior ability to think graphically fits this model.

Studies have concluded that the left brain is dedicated to analytical tasks, that are characteristic of linear, numerical-type calculations – forms of analysis that quickly converge to a solution. The right side, however, is thought to have characteristics that are much harder to identify. The most accepted is the processing of graphical, symbolic data. The responses are intuitive where the data may also be dynamic, with many dependent variables and solutions that do not easily converge.

Traditional teaching is almost exclusively left brain – numerical, formulaic and with little attention paid to the qualitative skills. When considering the early stages of the actual design process in the office, however, they are almost exclusively right brain. None of the parameters (cost, size and shape) are clearly known – each influences the other. This non-linear process uses graphical means of conceiving the structure. Only once this has begun to form are the left-brain skills applied. Therefore, the line of attack that appears is - if the computer can supply all the left-brain skills, then, perhaps the concentration is needed in teaching the right brain skills directly.

2.6.2 An Integrated Course Curriculum

The idea of carefully interconnecting the analytical courses with basic design is strongly encouraged by Bjorhovde. He used the example of providing a materials oriented, code-based elementary structural design course. The author's instant concern here is that this approach could have the negative effect of inviting rote learning. Bjorhovde did expand on his policy, however, stating that the education of structural analysis can not stand alone, with modeling techniques and structural response being divorced from the materials of the structure and its physical elements. He has the worthy desire to ensure that future engineers can make the extrapolation from models to reality.

An important warning raised by Bjorhovde in his paper is that the nature of structural analysis has now developed to the point that there is almost no limit to what can be analyzed. This is obviously a very exciting liberation, but the students must not be allowed to lose sight of the practical implications of the modeling. Sometimes the students and engineers, almost too enthusiastically, leap onto the computer straightaway, hence reducing their ability to think independently and practically. Students should be encouraged to regularly wonder "does the answer make sense?"

Fortunately even with this concern about the computer's role, Bjorhovde still believes that a correct balance can be met, by paying attention to the theory-to-practice connection and working to ensure students develop a healthy questioning attitude. The student should be both reminded and reassured that nothing should be regarded as flawless or 'exact' and any solution can always be improved.

2.6.3 Teaching Approximate Solutions

Beaufait's approach is also good and of a similar vein to the other writers discussed, however there is one important issue raised. He believed that although an important component for the students is to have exposure to the computer programs used by practicing engineers, at some stage these students must learn methods of approximation. They must study how loads and forces flow through a structure and how its system deforms under the action of the loads. Beaufait emphasized that approximate analysis is the student's necessary skill upon graduation, using it to check the computer solutions provided by the "black box".

2.7 Conclusion

Computer technology shall undeniably continue to take an ever-increasing role in structural analysis and design. It is crucial, therefore, that the Structural Engineering students learn to not only use the computer and software tools, but also to understand both the methods and limitations on which these programs have been developed and how the structures will physically perform. Concern has been raised by various educators and professional engineers about the poor achievement of this, judging the understanding of structural behavior by the current graduating engineer as poor. The graduates and students often accept the computers results on face value without even thinking about the predicted behavior.

Although the computer has been largely blamed for this decline in the engineer's skills, fortunately, it can also be acknowledged as being useful for more than just manipulating numbers. Providing a major shift in the education paradigm, the computer has great potential in teaching new concepts and ideas, and reinforcing them with the student through tutorials. As noted in Section 2.4, the challenge of this thesis is to act on this ability by beginning to create an effective educational computer package using the recommendations of Table 2.1.

From the discussion on the three approaches of Section 2.5, it can be concluded that to achieve this goal successfully, focus should be on realistic structural behavior in a qualitative, graphical and approximate format. Emphasis ideally would lie on behavior rather than analysis and the modeling techniques taught would actually demonstrate how they reflect the real conditions of the structure. An example application for this is connections – often there is no understanding of how these details appear in reality, and hence the student's ability to model the actual structure is limited at best.

Momentous should attempt to provide a human and social context for the learner. This will motivate the student to learn, and provide the ability to successfully interact with people. Finally, the package needs to encourage the student to think independently and apply fundamentals, thus providing a basis for professional judgement, such as knowing what is significant or insignificant in an idealization and why. From all of this, the student, hopefully, will begin to look at structures in a whole new way and question how they work. This skill will never leave them.

Chapter 3.

THE PEDAGOGICAL APPROACH TO TEACHING STRUCTURES

3.1 Introduction

Unfortunately, a problem that may often be seen with education at the university level is that although our professors may be great minds they may not always be great teachers. It is also extremely likely that many of them will have never had any formal training or guidance on how to educate effectively. For this reason, this chapter will look to the experts to explore the theories of education, hoping to apply them to the package, *Momentous* developed in this thesis, and thus creating a better product.

The majority of the material discussed hereinafter has been acquired from a class given by George Brackett at the Harvard Graduate School of Education. Auditing this course - "T525: Developing Educational Experiences using Networks and Webs" [6] - was extremely worthwhile. Although the emphasis was on networks, many of the issues and concerns were still highly applicable to *Momentous*, which aims at providing an integrated system of resources that incorporates the student and the multimedia environment of the computer.

One of the first points made by Brackett in T525 was that we need to remember the goal of educational technology. Its role should be to improve and enhance learning, thus in turn improving and enhancing teaching. The capabilities of the computer are a means, not an end, and as such are apart of a complex system. This warning, perhaps, can be seen as one of the oversights in Structural Engineering education, that may have caused some of the problems discussed in Chapter 2. Does too much emphasis lie in the computer and its methods, allowing the actual physical performance of structures to be forgotten about?

3.2 Designing for Education – the Philosophy, Theory, Principles and Criteria

Introducing two different theories to assist in designing a worthwhile educational experience, there is Theory One and the Tutorial Cycle. Both provide useful and complementary guidelines for the development process.

3.2.1 Theory One

Theory One as given by Perkins in Smart Schools [18], simply says:

> "People learn much of what they have a reasonable opportunity and motivation to learn."

Such a seemingly mundane and brief sentence can produce some very important implications. Fortunately, for us as the lay people, Perkins assists with these by elaborating on the statement. He states the bare basics for learning to occur, are:

- *Clear information* – Providing not just the knowledge needed, but explicit goals and expected performances. Explanations should be clear and concise, and accompanied with monitoring of the students' understanding of these explanations,
- *Thoughtful practice* – Allowing the opportunity for learners to engage actively and reflectively whatever is the material being learned,
- *Informative feedback* – Giving clear, thorough counsel to students about their performance, assisting them in developing more effectively, and
- *Strong motivation* – Using activities that are well rewarded, by their being, either, very interesting and engaging in themselves, or able to support other achievements that concern the learner.

Therefore, if the student is supplied with clear information about their performance through examples and descriptions, offered time to practice their performance and think about how they are approaching it, then provided with informative feedback, and finally taught from a platform of strong intrinsic and extrinsic motivation, their outcome of learning is likely to be successful.

To expand beyond these minimum criteria, however, Perkins also considers a few extra ingredients to be desirable to teach for understanding and achieve deep learning. These five components – Generative Topics, Mental Models, Understanding Performances, Levels of Understanding and Powerful Representations - have been earmarked, by research on current practice, and are together referred to as "Teaching for Understanding".

Generative topics are central, rich, interesting subjects, which are often interdisciplinary. Being easily accessible, they encourage questioning and exploration by the student. Patterns of thought or mental models – the second element – are useful to consider and apply as they enable understanding, just as they are also developed through understanding. Providing students with the opportunity to perform activities that will reveal their depth of understanding, is useful not only to the teacher for monitoring but also to the student as it encourages deeper thought and provides confidence in their abilities. The students are not simply regurgitating facts but are allowed to explain, exemplify, apply, justify, compare and contrast, etc.

The fourth desired element is to use various levels of understanding. Not all students learn well through the same methods, so providing multiple ways to engage with a topic, i.e. recall of content, problem solving, inquiry, application of principles to discovery of new ideas, gives them each the chance to acquire knowledge through their best route. Additionally, it gives the lesson more variety and a more stimulating environment. Finally, using representations, such as metaphors, both physical and mental, can be very powerful as they can express and concisely encapsulate essential aspects of a topic for students.

3.2.2 The Tutorial Cycle

The most effective learning environment available for a student is sitting one to one with a highly skilled tutor. No big surprises there, but how can some of the characteristics of this situation be emulated by *Momentous*. Brackett has developed the Tutorial Cycle in his classes, T522 and T525, to try to answer this. The theory proposes that every complete educational process include all the elements of:

- Presenting information related to the goals,
- Eliciting student action toward these goals,
- Assessing the student's action,
- Providing feedback to the student,
- Offering strategic guidance to the student, and finally
- Managing and motivating the process.

These elements maybe of any style or in any order, but they just must be present for the learning to occur.

3.3 Beyond the Basics

The basic pedagogical requirements have now been presented and meeting these criteria will indeed be a challenge. There are even more approaches, however, that should be considered as the project design becomes shaped and justified in more detail. Some currently recognized theoretical models, referred to as Theory Twos, have possible implications on the detailed design of *Momentous* and are listed with their key elements, in Table 3.1. Each method shall not be dwelt on further here, but instead the relevant ones shall be discussed in more detail in Chapter 5, as they are applied in turn to the package.

Table 3.1 "Table of Theory Twos"

Theoretical Models	Key Elements
Constructivism	▪ Discovery of principles through guided experiment, ▪ Invention of alternate systems of doing things, ▪ Meta-cognition (thinking about thinking or doing).
Developmental Perspectives	▪ Adapting "advanced" ideas to simpler contexts at younger ages, ▪ Making abstract ideas concrete through manipulables, ▪ Enhancing understanding of complex ideas through applications in familiar environments (simile, metaphor...).
Cooperative & Collaborative Learning	▪ Group activity through task division and subsequent peer instruction, ▪ Creating collaborative teams who work out their own processes.
Motivation Theory	▪ Enhancing opportunities for intrinsic motivation through responsive environments, ▪ Student involvement in teaching and assessment, ▪ Enhanced creative opportunities.
Multiple Intelligences	▪ Offering multiple symbolic representations, ▪ Engaging many modes of sense and action, ▪ Acknowledges diversity of human ability and consequent need to diversify instructional opportunities.
Situated learning	▪ Project orientation for concept and skill learning, ▪ Simulations and models, ▪ Analyzing real, relevant situations.

3.4 Conclusion

Having now reviewed the requirements of both the engineers in Chapter 2 and the educators, the criteria has been clearly defined. Satisfying them all is a tall order. If in the majority they are, however, then a highly successful package will be created. To begin the process, Chapter 5 shall aim to provide a well-designed and clearly defined project proposal. As anticipated, the requirements of Theory One, the Tutorial Cycle, Teaching for Understanding and Table 3.1, were referred to regularly during the creation of the proposal. The goal was to satisfy each item as if on a checklist during the design of *Momentous*. One last step is required before this Chapter, however, and that is a presentation of some important issues and considerations when using computers to communicate.

Chapter 4.

COMMUNICATING WITH COMPUTERS

4.1 Introduction

Communication design implies the design of pictorial and textual information to achieve maximum access and understanding. Obviously, it is an extremely important issue when designing computer and education tools, which encourage strong user involvement and visualization. Due to this, a brief review will be given of techniques and recommendations, anticipating their application in *Momentous*. An excellent reference for advice and guidelines on graphic and text design and the like is provided in The Non-Designer's Web Book, by Williams et al. [21].

4.2 Graphic Design

The aim of graphic design is to communicate content and function effectively. This is achieved in a potentially very stimulating manner by arrangement of the visual field, guidance to the hand and eye within that field, and exploration through an appealing visual environment. The setting should ideally be unified, varied and balanced, which respectively imply coherence, interest and fulfillment.

The screen is a product of a variety of graphic elements, be they text block or images. Hence, an infinite array of their arrangements is possible, with the many parameters for each element being:

- Location - within the screen and relative to the other elements,
- Size - typesize and graphic size,
- Style - typeface or artistic style,
- Emphasis or visual weight - through density and line weight,
- Texture,
- Color, and
- 'Whitespace' - a surprisingly important factor, with the amount and shape having strong visual impact.

These characteristics are what provide the graphical interfaces on computers with so much power. The assessment of their application and appropriateness is very objective, however therefore some principles are required to guide the lay person in design.

4.2.1 Graphic Design Principles

There are four powerful principles of graphic design – the use of proximity, contrast, alignment and repetition. They each will be discussed in more detail below, with the strategies for applying them summarized in Table 4.1. Each principle indicates possibilities in manipulating the parameters listed earlier in order to achieve a "good" design for communication. An important reminder, however, is that as the nature of design is to address multiple agenda, they cannot all always be satisfied at once. The designer has to compromise at least occasionally.

Aiding organization by grouping related elements, proximity can imply relationship. Relationship between elements is a quality that users search for and are disturbed when it is not found. The use of proximity also simplifies the screen or view, by creating visual "blocks", and in turn forming interesting whitespace around them.

Contrast adds variety by allowing different elements to actually appear different, hence improving visual interest and interpretation of the screen. Using similarity, such as proximity, aids organization and allows contrast to imply the variance.

Assisting in creating an impression of unity, alignment of graphic elements forms visual connections between them. This assists visual organization by directing the eye. The role of alignment is also important for both text justification and the arrangement of larger elements.

Finally, repetition provides unity and consistency to a screen by repeating elements. Creative use of it can also spark visual interest. An important characteristic of repetition, is that it denotes organization, and hence, care should be taken not to use with it unrelated elements.

Table 4.1 Strategies for Applying the Graphic Design Principles

Principle	**Proximity**	**Contrast**	**Alignment**	**Repetition**
Strategy	▪ aim for 3-5 points for the eye to rest upon per screen, ▪ avoid equal spacing of disparate things, ▪ vary spacing to indicate closeness, and follow the structure, ▪ create interesting spaces, avoiding centrality.	▪ use with confidence, making obvious contrasts, ▪ achieve by using all the parameters, i.e. size, style, color, etc, ▪ use strong elements sparingly, i.e. only for important features, ▪ create focal points and eliminate clutter.	▪ Create an explicit grid, ▪ Avoid mixed text alignments, ▪ avoid using center alignment, unless using a formal or stable effect, ▪ avoid aligning at a page edge – provide margins.	▪ emphasize consistent elements using bullets, typefaces, colors, icons, etc, ▪ consider adding repetitive elements, however excess should be avoided – simple and clean is best.

4.3 Web Design Issues

The topic of web design issues has been included mainly in order to provide an argument for why the author feels *Momentous* should perhaps not be a web-based tool. It is anticipated that the package will be used by the student for longer than just five minutes, therefore, if web access is desired it may be preferred that the package be accessible through downloading as a file from the web. This approach will not only allow greater running speeds; it will also overcome problems with browser variability and the like. The creators will have much greater control of the appearance and actions of the package on the user's computer.

Programming would no longer be limited to Java, if the downloading option were taken, allowing alternative languages, like C++ and Visual C++ to be used. Java is still a language that is very much in the early stages of developing its power, particularly in regards to its mathematical and analytical capabilities. C++ and similar, however, have much stronger libraries of functions and capabilities. The result would be the possibility of creating an even more integrated and exciting environment, in shorter time and with less effort.

Having made this comment, however, for the purpose of this thesis only, the example components developed for *Momentous* did use Java and a web based environment.

4.4 Interface Design

Interface design is an integral part of software design, applying its techniques has implications on the page layout and the "program" structure and navigation through it. Its three major principles are those of User Correctness, Least Astonishment, and User Centeredness. Elaborating on these, the first one is the simplest but also the most important; no matter what a designer may think the user is always right. All the other principles may be considered guidelines only, because if it doesn't work for the user then it should be redesigned until it does. Due to this, good designs have in-process testing.

Discussion of the second principle is more detailed, as satisfying it is perhaps not as obvious. The actions and results on a screen or when proceeding through a program should always be predictable to the user. Otherwise, people can just end up frustrated and confused. To achieve predictability, then the five qualities to be striven for are simplicity, clarity, completeness, consistency and robustness. The following provides a brief discussion on each with ideas on achieving them.

Ideally, simplicity is reflected throughout the whole software: its structure, layout, and navigation and task controls. The format should be apparent and easily comprehensible. Navigation decisions at any point are best if kept limited and straightforward, and the screen controls to achieve these movements and other tasks should be as uncomplicated as possible. Not only is it desirable that the controls appear to be simple, but they should also actually be so.

Other strategies to achieve simplicity of the controls include keeping the number of them to a minimum (ideally, less than seven) and clustering related one into blocks, especially if more than seven controls do have to be used. Additionally, separating control groupings of different functional types and using contrast to highlight the important controls are effective techniques.

The role of a control should always be immediately clear to users. Such tricks as making the most important controls prominent and using metaphors, through graphics, and the like, as aids are great ways to achieve clarity. There are many standards, such as scroll bars and arrows that can be exploited wherever possible to communicate a control's purpose quickly and concisely.

On any one screen of the program, there should always be adequate control to enable the user to accomplish their minimum set of desirable tasks. This reflects the completeness of the program – achieving what the user expects and needs it to do, and hopefully most of what they'd like it to do, too. Providing a minimum set of explicit controls to exit, go "back" or to the contents are good methods of satisfying this requirement.

To improve efficiency and reduce frustration for the user, all aspects of the program should appear and function consistently. If a set of elements is similar then ideally they look and work in the same manner, however if they aren't similar, then they should work differently. This goal can be achieved by using appearance, placement and operation to both support similarities in functions and distinguish between dissimilarities in them.

Normal human behavior is to make mistakes. This error should be designed for by anticipating user actions and preventing accidents. Constraining user input, by rejecting empty input or using popup menus, is one of the most effective measures for robustness. Another issue to be alert to is preventing unintentional navigation within the program – such movements that could take the user to surprising locations. This is more so a problem with web-based packages. The best approach, however, to assess robustness as has already been mentioned as being an essential component to any good design, is to test the package on novices from the target audience.

By considering these four goals of simplicity, completeness, consistency and robustness and their role in achieving a situation of least astonishment for the user, the importance of the principle can be seen. Diligent application of it will provide a friendly and worthwhile learning environment for the user.

Finally, the principle of user-centeredness; the user should always be placed at the center of the software or package. The three main aspects of this centeredness are control, responsivity and forgiveness. Users always like to be in control of the program, so the design should strive to give them this or at least the appearance of it. Ideally, the response of a user's actions is immediate, and if this unfortunately cannot be achieved then the program should be keeping the user informed. Without such a response or advice the learning experience from the program can be greatly, if not even totally, reduced. Forgiveness is related to robustness from the previous principle. As stated above, it is a fair assumption that users will make mistakes, hence a good program should provide easy means to correct them, wherever possible.

4.5 Conclusion

Many of the issues discussed in this Chapter may often seem obvious, yet they are still often overlooked. The exercise, therefore, of presenting them here is worthwhile as it clearly spells out many of the tricks and requirements to be targeted in the development of a useful computer based education experience. The author anticipates applying the principles given during the creating of the *Momentous* package.

Chapter 5.

THE ARCHITECTURE OF *MOMENTOUS*

5.1 Introduction

Chapters 2 and 3 have now laid out a strong argument for a new paradigm and techniques in the education of Structural Engineering, accompanied by a long list of requirements both technical and pedagogical. Together with the material from Chapter 4, appropriate methods for transferring knowledge by computers, the preparation is done. It is time, therefore, to present a detailed framework of *Momentous*, setting about achieving as many of the aforementioned goals and requirements as possible.

5.2 The Audience or Learners

Before providing detailed discussion on the elements of the package, it is vital to clearly establish the audience for *Momentous*. This clarification will enable correct focus and attention of the approaches applied. The audience for this package will be undergraduate students in their 3rd year with a major in Structural Engineering. Their incoming experience is expected to be in elementary statics; able to understand equilibrium, stability and stress-strain behavior, develop moment and shear diagrams and calculate displacements for simple beam structures – both determinate and indeterminate. To ensure all the users enter the program with an approximately common foundation, an optional section with review material will be available.

The students will be inquisitive and independent learners. Although a reasonable assumption of the "typical" engineering undergraduate is that they are already comfortable with computers and use them with relative ease, the development of the package will not be based on this. As computers are such a strong part of our lifestyles, they should be as easy and pleasurable as possible to use, bending to our will rather than us conceding to them. Therefore, the package will be developed for its use to be intuitive, encouraging strong involvement in the learning rather than the tool.

As a clue to developing the learning motivation aspects of the package, it is hoped that the users' interests would be structures of varying types – from large buildings and bridges to unusual specialized projects. The attractive visual fields supplied by the package will advance this. Finally, the students may have some hesitance or fear towards heavy mathematical and analytical procedures; hence, the emphasis will be away from this, instead developing qualitative understanding.

5.3 The Learning Goals

Reiterating, the major goal of the program is to develop in the students an understanding of structural behavior to the level of intuition. It is anticipated that the student's interests will be sparked, encouraging them to explore creative structural avenues beyond the traditional realm of the education field. They will be instilled with the qualities of flexibility, independence and confidence, enabling them to work with others of different agendas in the construction industry, whilst displaying competency, amenability and new ideas. The student will develop the rich and new vocabulary of Structural Engineering, which is so easily forgotten about by the educators, in a comfortable, non-intimidating environment.

The developers are confident that the student upon finishing the material of *Momentous* will be inquisitive - creating and exploring new problems rather than just being capable of solving them. Their skills will be honed for qualitative reasoning, independent of the computer, identifying the correct problem and resolving it approximately rather than very, and possibly excessively, accurately. Additionally, the student will acquire the ability to be a practical thinker, developing the skills to idealize and model physical, unbuilt structures. The students' graphical and visualization skills will be promoted

Finally, without repeating the list of the desired more specific skills given in Chapter 2, it is assumed that if the students are to achieve the level of competence expected that they will have learnt all these skills through *Momentous*. In conclusion, the full list of learning goals is a tall order, but it is hoped that *Momentous* in time will be up to the task.

5.4 The Learning Environment

Firstly, before describing the more specific details of the student's surroundings when using the package, *Momentous*' context within the full undergraduate curriculum needs to be considered. There are two approaches to employing the package at a University. The first is to assume that it will merely be incorporated into the existing degree structure and the second is to allow overhaul of the curriculum, integrating the package as an important part of the process. The later option, though radical, would allow reassessing of course material and its emphasis – in line with the discussion of Section 2.5 – to potentially use the package most effectively with focus on behavior. For the purpose of this thesis and the incredible freedom and wide variability allowed by this approach (it could easily be a thesis in itself), it will not be discussed further here. To provide light on the most probable context for the package, however, some deliberation will be provided on the first approach.

Using the requirements of the Civil Engineering Department at the Massachusetts Institute of Technology (MIT) as a guide, the subjects with their description, required for a major in Structural Engineering are given in Table 5.1. These classes will provide the students with probably their only exposure to Structural Engineering related topics. From assessing the course descriptions, it would appear that the introduction of *Momentous* would be most appropriate during the Structural Analysis class (1.50).

As has previously been mentioned in Chapter 1, alternative computer educational packages are available with the most relevant, with respect to *Momentous*, being Dr Beam and Dr Stress by Miller et al [14]. These accompany text by Gere et al, "Mechanics of Materials" [11], and would therefore be used in the Solid Mechanics course (1.04). The focus of *Momentous* will then be to continue and elaborate on the principles developed in Dr Beam, during the continuing course on analysis and structural systems.

Table 5.1 Course Requirements for Structural Engineering at MIT

Class Order	Subjects	Course description from MIT Course Catalogue [13]
	PREREQUISITE	
1	8.01 Physics I	Introduces classical mechanics. Space and time: straight-line kinematics; motion in a plane; forces and equilibrium; experimental basis of Newton's laws; particle dynamics; universal gravitation; collisions and conservation laws; work and potential energy; vibrational motion; conservative forces; inertial forces and non-inertial frames; central force motions; rigid bodies and rotational dynamics.
1	18.01 Calculus	Differentiation and integration of functions of one variable, with applications. Concepts of function, limits, and continuity. Differentiation rules, application to graphing, rates, approximations, and extremum problems. Definite and indefinite integration. Fundamental theorem of calculus. Applications of integration to geometry and science. Elementary functions. Techniques of integration. Approximation of definite integrals, improper integrals, and l'Hôpital's rule.
	REQUIRED	
	Engineering Mechanics and Materials	
2	1.04 Solid Mechanics	Static equilibrium. Forces in trusses. Stress, strain, and Hooke's law; introduction to stress-strain behavior of construction materials. Torsion in members of circular cross-section. Stresses and deflections in beams. Stresses on inclined planes and the use of Mohr's circle for plane stress. Design project using SAP90 software package.
3	1.59 Mechanics of Construction Materials	Develops an understanding of the mechanical behavior of construction materials. Includes study of elastic, plastic, and time-dependent behavior. Deterioration and failure mechanisms, failure criteria. Applications include cementitious materials, steel, timber, polymer, pavement materials, and composites. Materials selection.
	Engineering Analysis	
3	1.50 Structural Engineering	Introduces students to methods for the analysis of statically determinate and indeterminate trusses, beams, and frames. Examples are method of sections; conjugate beam method; moment distribution; etc. Determination of member forces and structural deformations (displacements); approximate methods; structural stability; energy methods (virtual force method); introduction to matrix methods.
4	1.51 Design of Steel Structures	Objective is to develop a solid background in the design principles of steel structures. Emphasis on contemporary design methods using load and resistance factor design. Includes design of structural members, joint, connections, and structural systems.
4	1.52 Design of Concrete Structures	Objectives are to develop a solid background in the design principles of concrete structures. Emphasis on contemporary design methods using ultimate load design concepts. Includes design of reinforced concrete members for bending, shear, and axial loads, prestressed concrete, and structural systems.

With the package's more global context clarified, the learning environment for the student on a more personal level will now be considered. Although, *Momentous* is expected to be a major integrated component of an undergraduate class, it will be primarily self-sufficient, requiring no external assistance from a tutor, professor or net support.

The student is envisaged as using the package, with minimal human support, on a personal computer working alone at his or her own pace. Other environments for *Momentous*' application can be at school in a computer laboratory, possibly with tutor support or by the lecturer in the classroom. The resource accompanying the computer software, with maximum possible integration, will be a textbook. The book will include guidelines with detailed descriptions, background information and exercises to steer learning and support the onscreen progression.

Further discussion on the package components is provided in the next section. One final point to note however, is that sufficient freedom within the package is anticipated in the long term to allow professors to also develop their own exercises for class demonstrations, etc.

5.5 The Elements of the Package

The learning environment package will consist of various components, ideally integrated to allow optimum learning and utilize the capabilities of current technology. These elements are (i) content material, (ii) a virtual library, (iii) a simulator and finally, (iv) a builder tool. The content material can be presented through the traditional text format, with maximum incorporation with the simulator and examples. The use of text on screen however should ideally be kept to a minimum.

People have an aversion to reading from the screen, usually only skimming the text, hence, not obtaining its full import. Text in the majority will be presented, therefore, through an accompanying book as mentioned in the previous section. A more interesting approach, which utilizes the opportunities of today's technology, is the simple use of audio, and even possibly video. A great deal more information can be effectively imparted to the user through short oral segments. Wherever possible this technique will be employed.

The virtual library will be a database of technical literature, design information, case studies and images. It will have the power to be searched as an independent system or cross referenced to by the other package elements. The images and case studies will be chosen and then used to display interesting and apparent loads and behavior, effectively providing a slide show. It is anticipated that through this introduction to real structures, an appreciation and awareness of the built environment will be instilled.

The simulators, called dynamic figures, will be interactive images, i.e. applets, created using Java or Visual C++ depending on the anticipated program platform. The response to the user's actions will be instantaneous. Integrated with these figures, providing guidance, useful comments and lessons, will be text/audio clips and practical and applicable real life images, as examples. There will be two roles for the dynamic figures, firstly the learning mode, providing fundamental structural examples, and secondly exercises, giving self-assessment and exploratory opportunities, as an interactive tutor.

Lastly, the builder component of the package is aimed at providing rapid prototyping of simple structural systems, with both flexure and axial elements. It will essentially be a basic structural analysis package with the emphasis on providing instantaneous qualitative results and graphical images rather than actual quantities, though they will be available. The builder will be especially useful when teaching and experimenting with modeling techniques.

5.6 The Pedagogical Approaches and their Inclusion in *Momentous*

From the discussion of Chapter 3, it is clearly apparent that for the package to be successful in educating then it is must satisfy the requirements of Theory One and the Tutorial Cycle. As was also discussed however, more detailed pedagogical approaches need to be selected to justify and clearly form the design. Various models from Table 3.1 can be chosen and used collaboratively. It is acknowledged, however, that not all of the elements of each approach can always be met and some compromise will be needed. For *Momentous*, the major theoretical models to have been selected for their relevancy are Motivation Theory, Constructivism, Multiple Intelligences and Situated Learning.

Applying Motivation Theory is rather an obvious one, as the interactive environment of the simulator provides a responsive and hopefully exciting and interesting environment that should intrinsically motivate the user. With the accompanying guidelines and exercises, the instantaneous response to the user's choice, and the ease in making it, should encourage progression through the process or lessons. The freedom to make one's own decisions and play with the variables in each exercise, which are integrated with real examples, should stimulate creativity and practicality. These qualities will hopefully be encouraged even further later in the process by the builder component.

The Multiple Intelligences are applied by the use of multimedia and interactive learning tools in the package. Adopting this approach engages an assortment of the student's senses and actions. Using both graphical and numerical representations of the same results, reinforces the user's graphical skills and caters for the variety of methods people use to interpret and learn the same thing.

Employing the theory of Situated Learning requires providing a learning environment with authentic contexts. This is being achieved by the incorporation of case studies, real images and relevant examples into the exercises. Maintaining the real and physical issues enables the needs and practices of Structural Engineering to be highlighted, giving the knowledge and skill being learned context, texture and relevance. The dynamic figures and builder also satisfy the Situated Learning theory by providing models and images with genuine and practical applications.

Finally, satisfying the theory of Constructivism is done merely using guided exercises on the interactive dynamic figures. The coaching of this process, with reinforcement from the other elements of the package, will still allow relatively independent experimentation and, hence, enable the user to discover and demonstrate Structural Engineering principles themselves.

Having now displayed *Momentous*' abilities to satisfy various pedagogical approaches, its effectiveness in fulfilling the elements of the two basic theories – Theory One and the Tutorial Cycle still need to be demonstrated. The main characteristics of the package that do this are the simulation, interaction and experimentation capabilities. Additionally, the chosen examples and issues will aim to be realistic and practical, presented through a progressive, easy and highly visual process.

Verifying the packages ability to fulfil the basic ingredients in further detail - both content, learning goals and expectations will be presented clearly, through onscreen text, audio clips or the accompanying textbook. The dynamic figures and builder will permit the student to actively engage with a problem, encouraging reflective thought through the opportunity to adjust onscreen variables and the progression of exercises. From the strategic guidance and instantaneous response of the program, the students will be able to assess their action and receive intrinsic feedback. Careful design of the exercises for the program will achieve effective assessment, contributing feedback that is more worthwhile. Finally, the adequacy of *Momentous* in supplying solid and effective motivation has already been well argued earlier in this section.

In an effort to provide the student with deeper learning, the rules of "Teaching for Understanding" need to also be aimed at. The selection of examples and case studies will be based on their worth as productive, interesting and accessible topics. Multiple opportunities will be available for displaying depth of understanding, from contrasting and comparing exercises to activities requiring explanations and applications of principles learnt. Accompanying these approaches will also be a variety of modes to engage with a given topic, from the dynamic figures to the images and audio accompaniments.

The last ingredient, powerful representations, will be the one best satisfied by Momentous, applying good images and interactive figures should be able to give the student both strong physical and mental models. Ideas can be reiterated with visual impact, the package format permits easy reference back to previous examples and embellishment of them with new images and ideas. Graphical representations have the wonderful ability to produce the essence of an issue very concisely, if not instantly.

5.7 Conclusion

A worthwhile proposal for the new educational package, *Momentous* has now been attempted, providing details on everything from the learning audience and environment to the goals. The various elements of the package have been introduced with some discussion on how they satisfy the pedagogical requirements.

From this presentation of material, the line of attack being adopted in the development of *Momentous*, if successfully implemented, would appear to have the potential to provide a highly effective and stimulating learning tool for structural behavior. All of the basic requirements for learning to occur are being provided and, additionally, elements of a variety of pedagogical approaches will be satisfied in a non-conflicting environment.

The next step is to now proceed beyond this level with a more detailed assessment of the learning material and actual examples. Chapter 6 presents this with deeper discussion on the package elements and their application in an integrated platform.

Chapter 6.

IMPLEMENTING A PRODUCT

6.1 Introduction

Chapter 5 has introduced a thorough framework to work by. In this Chapter, the details begin to be examined, and in so doing, the difficulties and problems are uncovered. More excitingly, the product can be demonstrated. At last, the design for transferring knowledge to a user on a particular topic can be presented to the reader.

The design methods and considerations for organizing the information conceptually for learning are discussed in Sections 6.3 and 6.4. Examples are provided in Section 6.5. Firstly, however, decisions were required on the content material to be taught. Section 6.2 provides attention to this with a proposed curriculum. The last Section of this Chapter provides an involved deliberation on the concerns and problems of including assessment in the package.

6.2 The Curriculum Material to be Covered

The first question that obviously arises when developing such a package, as *Momentous* is what information and material should be included. This applies at both the global level of the course curriculum and locally for the details of each item taught. Within this section, we will consider the aspects of the curriculum. During this process, often the most important question is actually, what shouldn't be taught.

Already in Chapter 2, some time has been spent on the dilemma of which analytical methods should be excluded in a Structural Engineering program. The author at present does not propose an ultimate solution (if there is one!) to this beyond what has already been discussed. Her only counter is to emphasize that the most significant goal of *Momentous* is to maintain a focus on structural behavior. Hence, this approach will be taken wherever possible within the program's future development and currently no decisions have been made on what, if any, analysis methods will be included. A possible line of attack could be to avoid including the analytical methods whenever practicable and providing the package more as a teaching aid to complement the classroom, hence, leaving the decision up to the teaching professor with only recommendations being made in *Momentous*.

An outline of the curriculum material on Structural Engineering to be developed is provided in Appendix A. Due to its large extent, containing preliminary details on the proposed teaching format and sequence, the outline has had to be placed in this appendix. A simplified flowchart of the major sections, however, is given in Figure 6.1 as an overview. From this chart not just a feel for the material being taught is seen, but also its sequence to enable progressive learning. The process like any learning experience is quite nonlinear, so simplifying it is challenging. Following will be a brief discussion on the thought processes behind each section and their position in the learning process.

As stated in Chapter 5, the student will be assumed to have previously taken an elementary statics class. In the context of the proposed learning environment, therefore, the *Introduction* will essentially provide a review of this material already learnt. From this, existing knowledge will be confirmed, any misconceptions confronted and an even foundation to begin further learning on established. All of the basics are covered: from the nature of loading types, construction materials and structural members, to understanding simple structural responses. Throughout this section, the material will be kept at very much a qualitative and presentational level, with perhaps a few demonstration activities. The problem of foreseeing learner's misconceptions is interesting, as often progress for the student may depend more on discovering "what isn't" rather than just "what is".

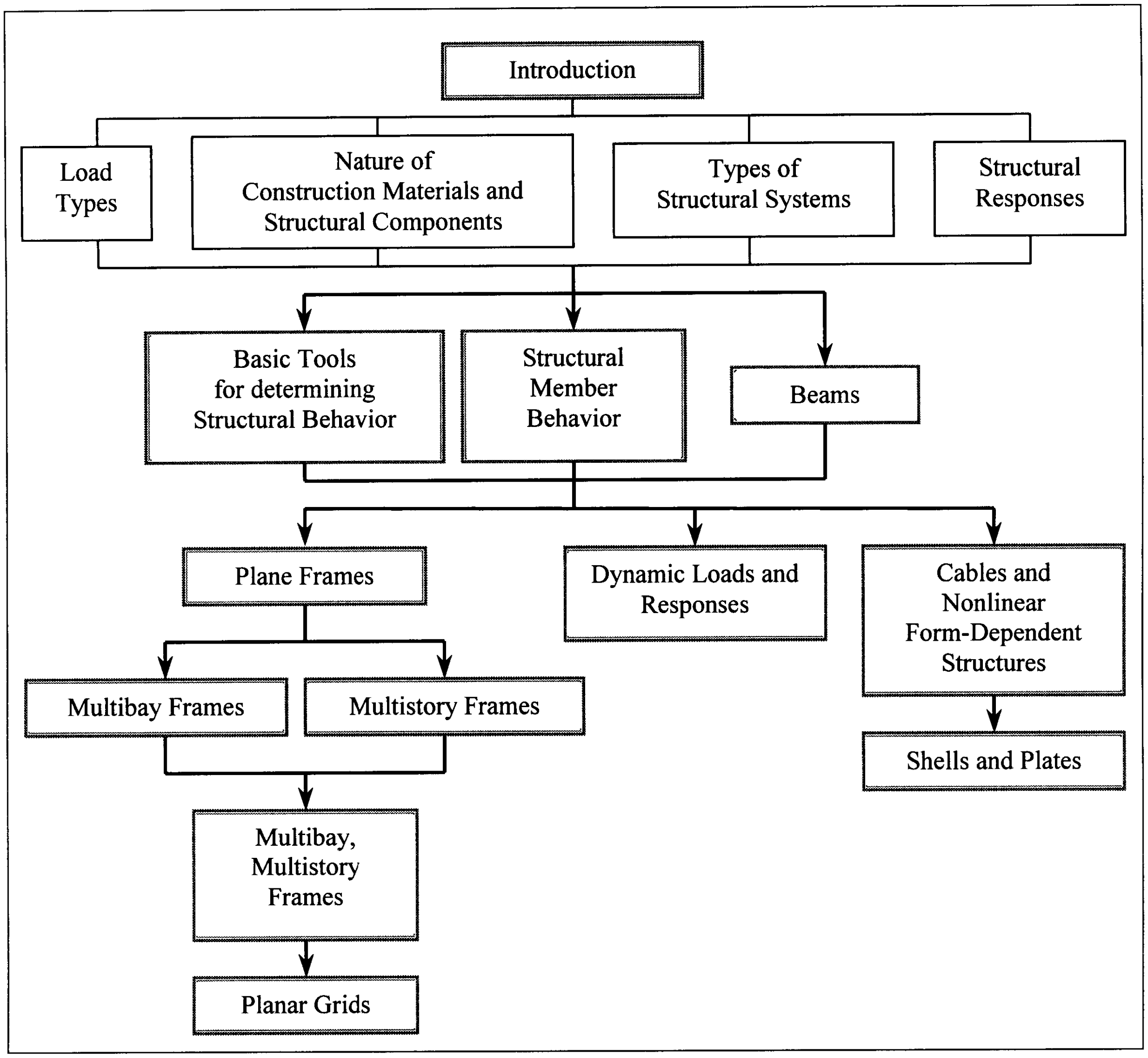


Figure 6.1 **A Flowchart of the main sections for a Structural Engineering Course Curriculum**

An additional role of the *Introduction*, as is always the case, is to provide a brief overview of future expectations of the package. This is an essential component as it allows the material to be placed in a practical and relevant context, and the student to begin to see their anticipated learning goals. For example, the various types of structural systems will be briefly introduced at this point, providing significance to the learning by viewing a larger picture.

From Figure 6.1, the next three sections are seen taught in parallel, as the understanding of all of them is so intertwined it is difficult to separate them. Firstly, *Basic Tools for determining Structural Behavior* and *Review of Structural Member Behavior* both continue to set out the basic theory and definitions, although the depth of presentation becomes deeper. The material presented during the teaching of *Beams* allows many of the principles and issues introduced in the other two sections to be quickly demonstrated and extended on. Hence, the *Beams* section has been placed in parallel with these other two in the teaching sequence.

Within all three of these sections lies an opportunity to introduce powerful and effective learning methods with simulators. Much of the material may have already been presented by tools such as Dr Beam, mentioned in Section 5.4. An opening, however, does exist for *Momentous* as it can elaborate and extend further upon many of the elementary principles in a far more integrated environment. In particular, the material to be covered by *Basic Tools*, where much of it is related to the issues listed in Table 2.1, is essential for a structural engineer to know well. Hence, it being properly taught and understood before the student can proceed onwards is extremely important.

Once the essentials are felt to be sufficiently instilled in the student, then new material can commence being taught. For the user to determine if this has been achieved and is ready for the new step, and similarly throughout the program at other transition points, some form of self-assessment will ideally be provided. If the results of these evaluations aren't satisfactory, the student will be encouraged to improve with extra exercises and supplementary material. Further discussion on the anticipated approach for assessment will be discussed in Section 6.6.

The new material to be covered will effectively start with *Plane Frames* and continue on working up to three-dimensional large Frames and *Planar Grids*. More than just a one-line topic the area of Frames is actually very rich and involved, as displayed by the detailed list in Appendix A. The topic allows deep discussion on various issues including stability and structural systems. Running parallel or as a finale to the material on Frames, etc. could be an introduction to *Dynamics*. This would discuss the loads and their cause, present simple one-degree of freedom models and highlight the critical effect of Dynamics on design.

Additional material to be taught in parallel to or after the Frames includes the area of Cables and Nonlinear Form-Dependent Structures as well as Shells and Plates. Cables and nonlinear forms though a challenging area can provide strong intuitive knowledge to the student through their unique behavior. All of these later sections of the content material when presented in *Momentous* will be heavily dependent on interactive graphical exercises and descriptions accompanied by text from the book.

From a first glance of the curriculum summary in Figure 6.1, some typical Structural Engineering education material may have been thought to be neglected, this is not the case, however, as seen by examining Appendix A. For instance, the reader is sure to have noticed the lack of an appearance by Trusses in the flowchart. This is due to the approach encouraged by the author's advisor, Prof. Connor, of considering trusses simply as a special case under the "Frames" umbrella. One of the developed examples to be discussed in Section 6.5 actually provides a small demonstration on how this might be done. Arches could also be taught in a similar manner.

There is other material that the author feels is essential and has not yet been explicitly covered by the curriculum lists presently provided. This is perhaps due to the topics' more conceptual nature, often requiring an accumulation of other skills learnt. For instance, the examination of load paths and developing good modeling techniques are such topics. Both of these skills should become second nature to a good fledgling structural engineer. Time dedicated to the education of them, even at the entrance level, will encourage faster understanding of structural behavior and extend into more creative consideration of structural systems and elements. Studying not just mundane typical building forms, but unusual configurations, such as interesting transfer structures, if kept simple, can provide encouraging enlightenment. An additional, worthwhile topic is examining building form, allowing the student to see how structure and load can govern and generate it. This is not merely an airy-fairy architectural notion, but one that can go beyond providing just understanding to invite motivation and creativity in the student, as well.

Having now studied the range and depth of material that should be covered by *Momentous*, the reader is now at last prepared to look at the implementation and presentation process with worked examples. The goal will be to integrate the curriculum topics building one on another. Reflection will be allowed during the introduction of new concepts and examples, through the recalling of past knowledge whenever appropriate. The approach will remain practical, teaching "how" not "what" by linking real examples and applications. Finally, the student will be encouraged to look at physical forms and think about how they actually work.

6.3 Developing the Elements of the Environment

The various components of the *Momentous* environment were introduced in Section 5.5 – the content material, a virtual library, a simulator and a builder tool. Within this section, more detail will be paid to the second and third elements of this list, discussing issues that arose during their development and future considerations that may be needed. The generation of the content material is largely based on the curriculum chosen as discussed in the previous section. While, the last element the builder tool is envisaged as more as an independent exploratory tool and will not be discussed further in this thesis, beyond what has already been mentioned.

6.3.1 The Virtual Library

As mentioned in the proposal, the virtual library is envisaged as a database of technical literature, design information, case studies and images. During the process of establishing this library, a division became apparent. Firstly, there is the selection of images – both static and animated – to use as visual teaching aids. Their use is seen less as in a stand alone "library" but as figures to be integrated into an exercise or lesson. The second branch of the library, simply referred to as the references, will contain all the other material. An analogy to much of it would be to the appendices at the back of a textbook.

The selection process of the images is based on their strong display of certain structural criteria or qualities. A reasonably comprehensive list of such desired characteristics is provided in Table 6.1. Already a collection of over 100 images has been made, with many of them demonstrating more than one criterion. From examination of Table 6.1, the pattern of requirements can be seen to reflect the teaching curriculum discussed in Section 6.2. In order to illustrate how this selection process was applied a few images have been provided in Table 6.2, with justification for their choice.

The material to be included in the reference section of the library will be useful and worthwhile, particularly as future design sources for the user. Example information includes everything from tables of unit conversions, material properties, typical loading types and values, and common steel section properties to formulae for obtaining the deflection, moments, shears, etc of typical beam arrangements. It will be helpful to the students to have many of the design criteria and limitations summarized and listed. A major benefit of setting this information into a database is its ability to be easily searched and recalled.

Another powerful teaching aid to provide in this section is a glossary of terms. It doesn't take long to forget as an engineer what an amazingly broad and rich language has been acquired during the civil engineering undergraduate education. Hence, there is often a large assumption by the professors made of the students, that they already know many of the technical terms. Unfortunately, this is not always the case even for very simple terms. This situation is seen as only getting worse as students continue to come from more and more differing backgrounds. If this problem isn't caught, therefore, students may be discouraged and quickly lose confidence by this feeling of inadequacy. Assisting in providing this vocabulary through a non-threatening environment should make learning so much easier and more comfortable.

Table 6.1 Example Qualities each Image might satisfy

A Sense of History **Construction Materials,** e.g.: ▪ Concrete ▪ Steel ▪ Timber ▪ Stone **Structural Elements,** e.g.: ▪ Columns ▪ Beams ▪ Torsion Elements ▪ Connections ▪ Arches ▪ Bracing ▪ Cables	**Structural Systems,** e.g.: ▪ Trusses ▪ Frames – including portal and gable ▪ Planar Grids ▪ Shells **Structure Types,** e.g.: ▪ Tall Buildings – with frame action or bending ▪ Suspension Structures ▪ Bridges ▪ Transfer Structures **Structural Concepts/Phenomena,** e.g.: ▪ Following the Load Path through Structures, including unusual paths ▪ Stability ▪ Consequences of pattern loading

Table 6.2 Examples of Images selected for the Virtual Library

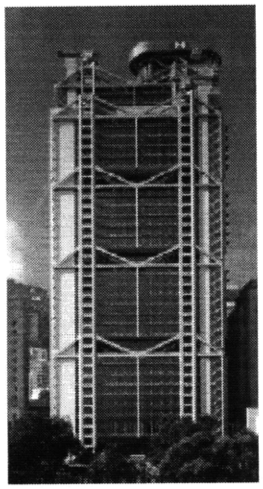
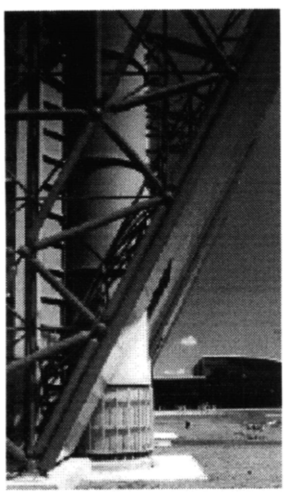
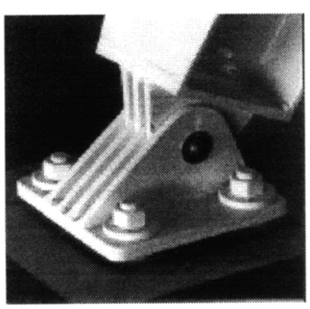
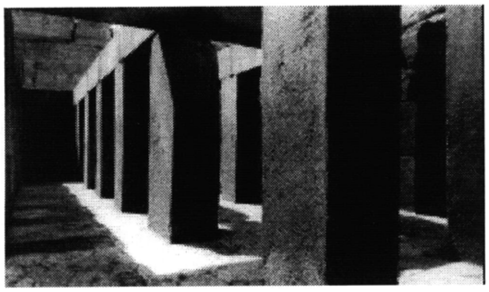
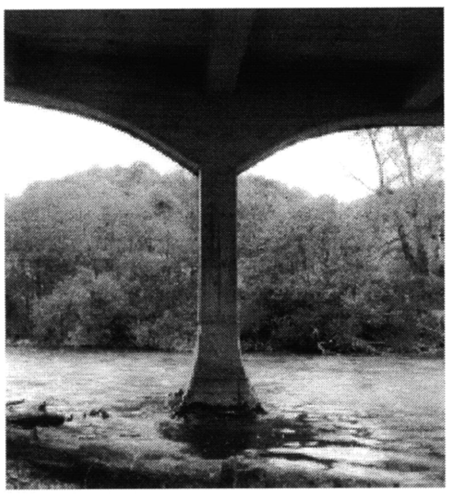
Image	Source	Justification
	The Hong Kong and Shanghai Bank, Hong Kong, 1987 Ref. [17]	Provides a good display of the load path through the building, including an interesting use of hanger ties/truss action with bending of the major column frames.
	Cogeneration Plant, Jamaica, N.Y. Ref. [1] Detail of a Steel Space Frame.	Example of a 3D truss, with clearly expressed pin joints. They have been emphasized by the tapering of the members into "ball" connectors. As a teaching aid, this can be a useful image to prove that the forces must only be axial with such details.
	Column Joint, by Renzo Piano Ref. [20]	A clear and attractive example of a pin joint detail.

Table 6.2 cont.... Examples of Images selected for the Virtual Library

Image	Source	Justification
	Chefren Temple, Pillared Hall, 2400B.C. Ref. [22]	Demonstrates the history of stone as a structural material, including how well formed and worked it was for its time. The design is strong, using columns and beams with short spans, hence demonstrating the stone's inherent property of low tensile strength.
	Birs River Bridge at Liesberg, 1936. by Maillart. Ref. [3] Detail from underside.	A great view of a concrete structure, with attractive and interesting forms, hence displayed the versatility of the material. The secondary members are seen as they connect with the primary beam, which is haunched at the maximum moment over the support. This also allows it to have a smoother transition with the column. The splayed column base spreads the load to the foundation more evenly.

6.3.2 The Dynamic Figures

Presently, the dynamic figures are being developed using Java applets, however there is the future possibility of using Visual C++ instead. The programming has been done by Gilberto Mosqueda. The figures are interactive, allowing the student to play with variables on a simple structural system and providing the solutions to these modifications instantaneously in a graphical form. For the exercises created to date and discussed here, all have simulated structural behavior. The three main characteristics regarded as essential for this qualitative learning, as promoted by Brohn, are the reactions, moment diagram and deflected shape. These were therefore represented in the solutions accompanied by the axial force, shear and rotation, wherever applicable.

The best manner of demonstrating the dynamic figures and their application is in the context of actual learning exercises. Further discussion on them, such as the variables and goals of each, will therefore be kept to a minimum here. Section 6.4 on the integrating of the packages components will provide better details.

6.4 Integrating the Elements

The secret to creating a successful and worthwhile learning environment appears to be in the integration and presentation of the package elements. The blending of these components is simply a part of the natural process as they want and need to complement each other. The challenge is in this, however, as structuring the material conceptually in an orderly and systematic manner is not easy.

In Figure 6.2, a proposed format for the incorporation of the elements discussed in Section 6.3 is made. The two major working categories to come out of this are the *Slide Shows* and the *Interactive Exercises*. The *Slide Shows* are lessons, using a practical and relevant context to expand upon and demonstrate principles and concepts of structural behavior previously taught. The *Interactive Exercises* are seen more as providing realistic simulations of structural systems, and encouraging exploration. Further discussion on both of these categories will be provided in the following two subsections.

The reason for the potential success of *Momentous'* approach lies in its ability to present a variety of discourses to the user – providing alternative encounters with new information, therefore, allowing better exposure and opportunity for all students to learn. Ideally, *Momentous* when combined with the classroom situation will offer this possibility, through various techniques of didactic presentation, orchestrated discovery (e.g., simulations), problem contexts with reference materials and examples (e.g., case studies), information interspersed with action, and multiple representations.

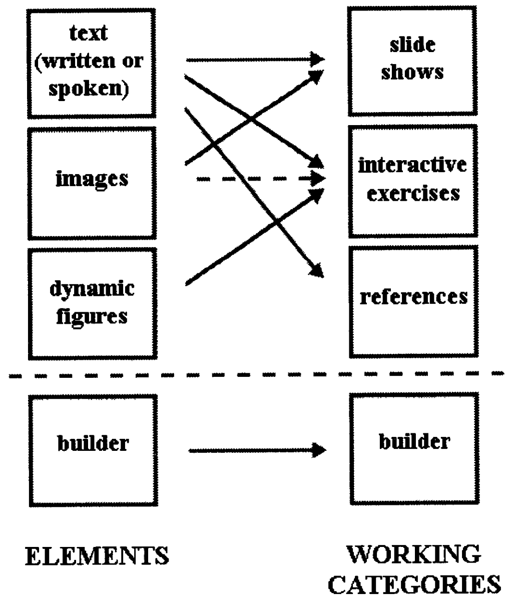


Figure 6.2 Format for Incorporating the Basic Elements of Momentous into Working Packages

Throughout all these techniques to providing discourse, it is very important to address complexity. Neglecting complexity allows students to make progress, hence when introducing new ideas, they, ideally, start simply and treat cases where only one concept or variable is salient. One drawback with this, however, is learners are often left with simplistic notions. Therefore, it is essential not to neglect complexity but to include it, with good learning support, when and wherever appropriate, thus encouraging the students to progress to the level of experts. Ideally, the development of the modules for both the *Slide Shows* and *Interactive Exercises* will follow this approach.

When preparing the individual modules of the package, i.e. shows or exercises, the most important thing to be initially established were the goals or purpose. Through the implementation of these, the importance of stating them in the final product became clear, as it enables the student to know the purpose of completing each module. Another vital, though small, issue to provide in all the modules was indication of the users progress through them. If the user doesn't know how much further they have to go in a module they may be easily discouraged and just drop out of the whole program completely.

The focus of the communication of information, both aural and written will always be relaxed, with a personal and friendly feel. The aim is to make the user comfortable in an environment that is conducive to learning. One of the wonderful freedoms of the computer medium is that it allows just this. An approach, more like someone speaking to the student – say as a tutor – in an informal manner, rather than as a lecturer or textbook with formal English grammar, can be achieved. In the proposal of Chapter 5, audio was stated as being the ideal use of information transfer, keeping the text on screen to a minimum. This, too, will be the plan for the final product, however for presenting examples in this thesis; screen text had to be relied on quite heavily. The relaxed tone has still, hopefully, been maintained, with each page being kept brief and scrolling eliminated wherever possible.

6.4.1 The Slide Shows

The *Slide Shows* are envisaged as a collection of images and words along a theme. They will be lessons that provide discussion about structural concepts and issues. Through them, it is anticipated that reflective thought will be encouraged, as they guide the user through new ideas by gathering together knowledge they have already acquired and demonstrating it in practical situations. This final aspect is very important - the shows are necessarily a progression upon the student's past learning. With this dependence on prior knowledge, the benefit of allowing an introduction to a new more advanced topic may often be available – possibly at an earlier stage than would normally be expected for the student. The setting is to be as visually exciting as possible using animated figures and colorful, interesting images.

Examples of themes for the *Slide Shows* include stability, tall building structural systems, and earthquake design and damping. For instance, considering the stability topic in more detail, discussion could be provided on its principles, firstly at an elementary level and then carried through for a more complex system. The impact of stability on the design considerations could then be covered; for example, the effect on scheme decisions. The pros and cons of braced versus framed systems may be debated – discussing the benefit of simpler connections for a braced structure over the more expensive connections, though free wall space, of a fixed frame.

This approach allows a review of material to be provided – bringing together a collection of seemingly unrelated topics and connecting them together into one whole system. A more detailed example of this than those just discussed has been made and is presented in Section 6.5.

Naturally, there will be some overlap in the topics covered by each show. The dilemma is, therefore, as the package is further developed, how much overlap is desirable. Obtaining the appropriate balance has become yet another challenge within the project. Though not wishing to complicate the material, overlap is important as it can encourage continuity and relevance to the student's learning.

6.4.2 The Interactive Exercises

The real power of the program, *Momentous*, will be in the *Interactive Exercises*. Their effectiveness, however, depends on their being placed in a context that is both interesting and practical, yet simple to use. It is important, therefore, that they are well annotated and self-explanatory. The whole reason for using such tools on the computer to replace actual laboratories is their potential ease and cost effectiveness in demonstrating an engineering principle by a quick and obvious manner.

While the *Slide Shows* will be more in the form of an informal lecture, the *Interactive Figures* are seen to provide detailed learning of a given engineering principle or concept. Their success will depend mainly on the dynamic figures, or applets. Content material will be provided in the form of guidance, explanatory notes and questions. The aim is to encourage exploration by the student; hence, the challenge will be achieving the correct distribution in the type of questions and amount of control given.

The role of the images in the *Interactive Exercises* is seen more at the completion of an exercise, therefore only a dashed line is used in Figure 6.2. An image will be provided when it is seen as an appropriate example to encapsulate the ideas being taught and encourage reflective thought. By this approach, the images will also maintain a practical context and perhaps provide motivation for further learning of the topic.

As each exercise is developed, a set of variables is decided upon based on its objectives. To maintain the focus of learning it is important that these variables are well chosen to allow the desired control and exploration within the exercise. A demonstration of this process can be seen in the worked examples provided in Section 6.5.

Topics that could be covered by the *Interactive Exercises* include superposition and indeterminacy (as shown in the example in Section 6.5), the implications of pattern loading on structures and the effects of varying stiffness in a frame. The modeling of cable stayed bridges could be explored, introducing the concept of springs. Comparison can be used as a powerful tool for example with beams and columns, or trusses, arches and frames. While, further investigation into indeterminate structures could be provided, for example, by an exercise that requires the user to first note the degree of indeterminacy for various structures and then reduce them to determinate ones through the release of their joints. This last idea along with many others was explored in Brohn's excellent book [8].

To demonstrate how the many recommendations and requirements for the *Slide Shows* and *Interactive Exercises* may be accomplished, worked examples have been presented in Section 6.5.

6.5 Examples

Three examples will be provided – one *Slide Show* and two *Interactive Exercises*. The second of the *Interactive Exercises* is still very much in the preliminary form, yet has been included as a demonstration, referred to in Section 6.2, of an alternative method to introducing Trusses to the students. Beyond providing an investigation in to the adopted techniques, these examples also display the proposed structure or format.

6.5.1 "Seeing Load Paths"

The *Slide Shows* example has the theme of "Seeing Load Paths" and consists of some 30 text slides, plus images. The first slide is given in Figure 6.3 to initiate discussion on them, however due to its size, the full presentation is provided in Appendix B and on the accompanying compact disk (CD). Beyond the first and ultimate goal of demonstrating structural behavior, the other aims in mind when developing this module were:

- To encourage the following of force flow and load paths through a building or structure,
- To impart a better understanding of stability,
- To provide a larger macroscopic view of structures, accumulating and consolidating understanding of the principles of statics, stability and determinacy,
- To initiate concerns in modeling and design, thereby encouraging creative engineering.

The user is assumed to have a knowledge level that has already reached at least an elementary understanding of frames, trusses and load types, prior to their beginning this *Show*.

Before describing the process taken during the production of this *Slide Show*, the proposed typical format will be examined. From the first slide given in Figure 6.3, the screen can be seen to consist of four frames – Title, Text, Projector and Global Controls.

The Title frame in the top left-hand corner, contains the text "Seeing Load Paths". The Projector frame dominates the screen to the lower left, displaying all the images called on in the Text frame through underlined text links. This Title Frame in turn provides the content material of the module. Navigation controls for within the module are provided in the bottom of the Text Frame, also indicated is a page counter to enable the user to monitor their progress through the module. Finally, the Global Controls frame obviously contains the navigation controls for the whole program. The current format only allows movement back to "Home" and the contents pages for the *Slide Shows* and *Interactive Figures*. The Global Controls Frame like the Title frame remains unchanged during the module. The arrangement of the Control Frame is preliminary, as it is expected to evolve to include access to other future capabilities of the program as they develop, i.e. the proposed Glossary of Section 6.3.1. Regardless of the final arrangement, however, the essential need for a quick escape from the program for the user will be provided at all times.

Four structures were examined in detail in this *Show*; the first was a simple roof structure that displayed the member hierarchy well. Deep discussion was provided on the member actions and the force flow, and by the end of it, a deviation was made into reviewing bracing and stability. This, then, led into a relevant comparison of three simple frames, allowing the user to consolidate and expand upon previously acquired knowledge.

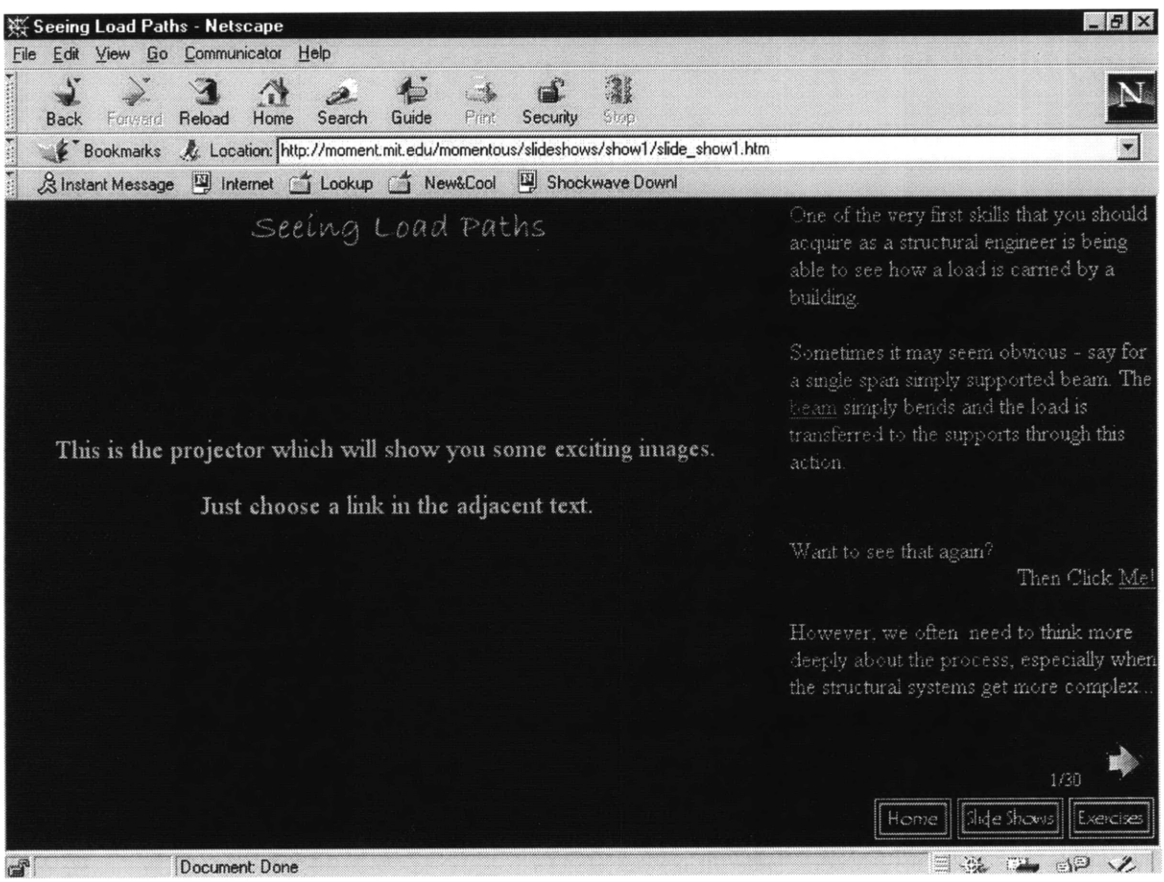


Figure 6.3 The First Screen of "Seeing Load Paths"

This section of the presentation began with the example of the John Hancock Tower in Chicago. Simplified modeling techniques and visualizations were suggested. Next, animated images were used to simulate the deformed shapes of the simple frames under single point loads. Time was also spent on considering the stress action of each member, encouraging further understanding of the behavior. As provided throughout the *Show*, students were hopefully encouraged to have reflective thought by questions that were supplied (and answered).

The purpose of the examination of the three simple frames was to acquire the three essential tools needed for understanding load paths, as follows:

1. Check for stability,
2. Pass the load from the point of application down to the ground, and
3. Consider the action of the elements (tension, compression, bending, etc) to achieve this.

After the review, the other three structures were examined using the tools learnt. With similar complexity, each structure had a different configuration and approach to force flow. All four of the structures in the *Show* were selected for their explicit display of the working structure and their creative and/or aesthetic appeal. For each structure, the assumed dominant loading conditions were stated, as well as the architect's name where appropriate. Detailed discussions were provided on the force flow, the action and role of each element, and how the structure may be simplified or modeled for analysis. If possible, an alternative scheme was sometimes suggested, to encourage the student to develop thoughtful practice.

The conclusion to the module was brief, merely reiterating the three important tools presented earlier. Unfortunately, no opportunity was supplied to allow the student to apply what they had learnt. This obviously violates the requirements of Theory One and the Tutorial Cycle, as the author feels it does not provide satisfactory feedback to the student of their understanding. Hence, this assessment is very much a desired aspect that at this time has not had its approach resolved and will be discussed further in Section 6.6.

6.5.2 "Point Loads on a Simply Supported Beam"

The second example to be presented is an *Interactive Exercise* entitled "Point Loads on a Simply Supported Beam". The purpose of this module is:

- to observe the behavior of beam under a point load,
- to demonstrate the Principle of Superposition,
- to conceptualize continuous spans and indeterminacy, by using a positive and negative load together on just a single span, and
- to introduce the possibility of control.

The presentation consists of 25 slides, presented in Appendix B, Section B.2 and on the CD. The first two slides are illustrated in Figures 6.4 and 6.5. The *Exercises'* format is similar to that of the *Slide Shows*, except the Title Frame has been moved over to the right. Otherwise, consistency between them has been maintained as much as possible. The Dynamic Figure is displayed on the Projector Frame.

The level of understanding assumed of the student prior to their commencing this exercise is very elementary; expecting knowledge of statics and stress-strain behavior, including being able to derive the shear and moment, etc. for a simply supported beam.

There are four variables in total, two for each load – one being for magnitude and the other for location. No units are used, with the location variables being dimensionless with respect to the length of the span. The loads can both be negative or positive. Presentation of the diagrams is in the mathematical order of their derivation, i.e. Shear, Moment, Rotation and Deflection, with results drawn for each load and their total. The reactions have not been displayed in this *Exercise*, as including them caused too much confusion on screen. The presence of the shear diagram is felt to be sufficient for this case in informing the student.

Employing the goals of the *Exercise* as a framework, each was developed into a lesson with detailed explanations and guidance. The students are encouraged to explore different ideas and concepts through suggestions given whenever seen fit; for instance, actual values are provided during the lesson on Superposition, to ensure the student goes through the full thought process. During this lesson, an example or deviation is also given using a simple image to contribute context.

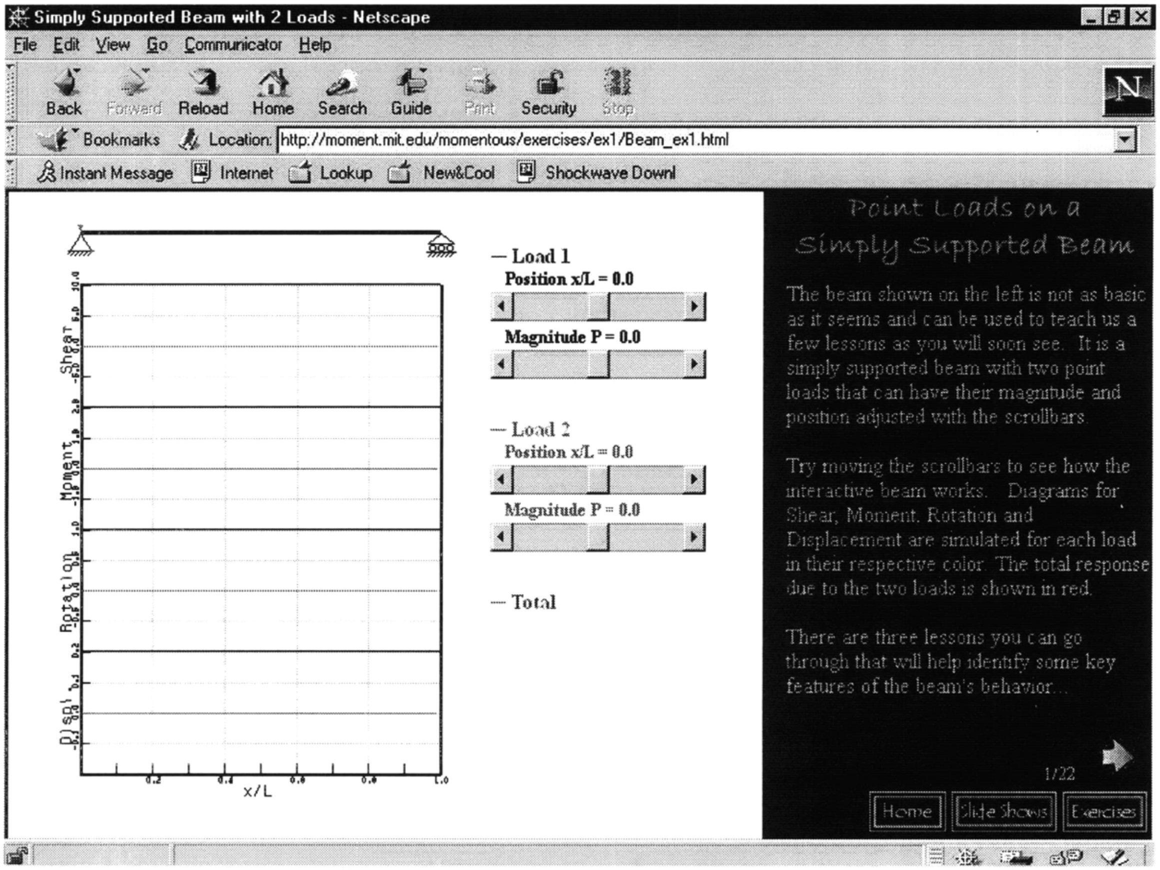


Figure 6.4 The First Screen of "Point Loads on a Simply Supported Beam"

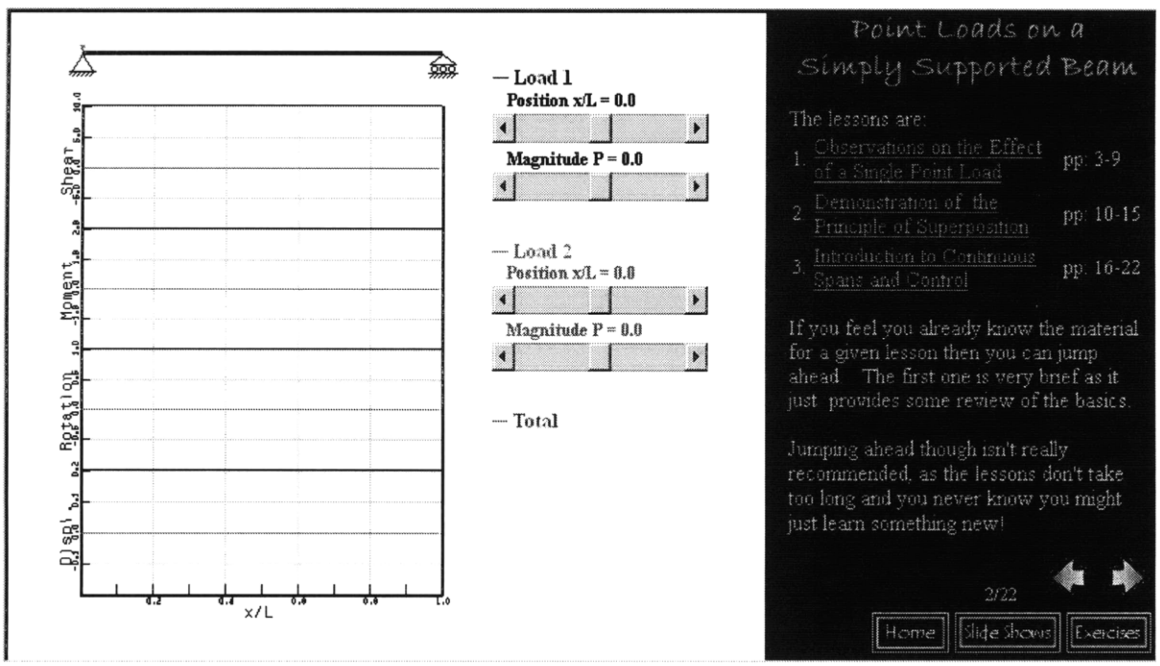


Figure 6.5 The Second Screen of "Point Loads on a Simply Supported Beam"

The last lesson introducing continuous spans and indeterminacy leads well into a corollary *Exercise* that involves a cantilever beam with two point loads as illustrated in Figure 6.6. This next *Exercise* would extend on many of the ideas of "Point Loads on a Simply Supported Beam". For instance, the critical behavior characteristics of a cantilever can be demonstrated and Superposition may be used to easily find the total moment due to a load A on the back span and a load B on the cantilever. Then for a given load A, the student could be asked to find what size and/or where load B should be to control the deflection under load A to within a certain limit. Hence, the discussion on control and indeterminacy is continued and enhanced with a new example.

As with the *Slide Show* example, no assessment was provided at the end or throughout the Exercise, naturally to its detriment. With the quality of the *Exercises*' abilities, providing problems for the student to prove their understanding should be easy to achieve. Possible solutions to this are discussed in Section 6.6.

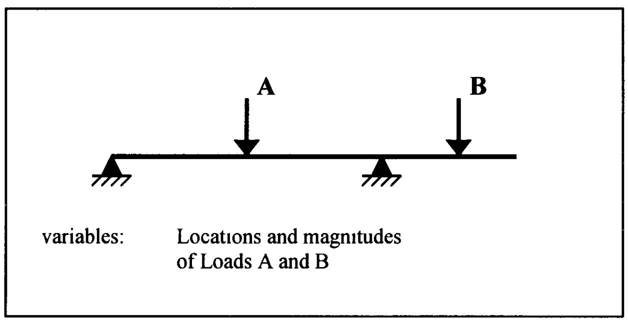


Figure 6.6 Scheme Sketch of the Dynamic Figure to be used in the next *Interactive Exercise*

6.5.3 "Is it a Frame or is it a Truss?"

This third and last example, "Is it a Frame or is it a Truss?" is being provided only at its scheme level in order to explain, as already mentioned, how Trusses can be taught as a special case of Frames. The Dynamic Figure would appear similar to that shown in Figure 6.7. The two figures both represent the same frame, the one on the left is used to show the loading conditions, reactions and deformed shape, while the one on the right displays the Axial Force, Shear, Moment or Rotation, depending on which was is selected from the menu. Each provides an informative graphical display of the structure's behavior. Including the reactions for this example is important to provide a powerful representation of the effect of varying the support conditions.

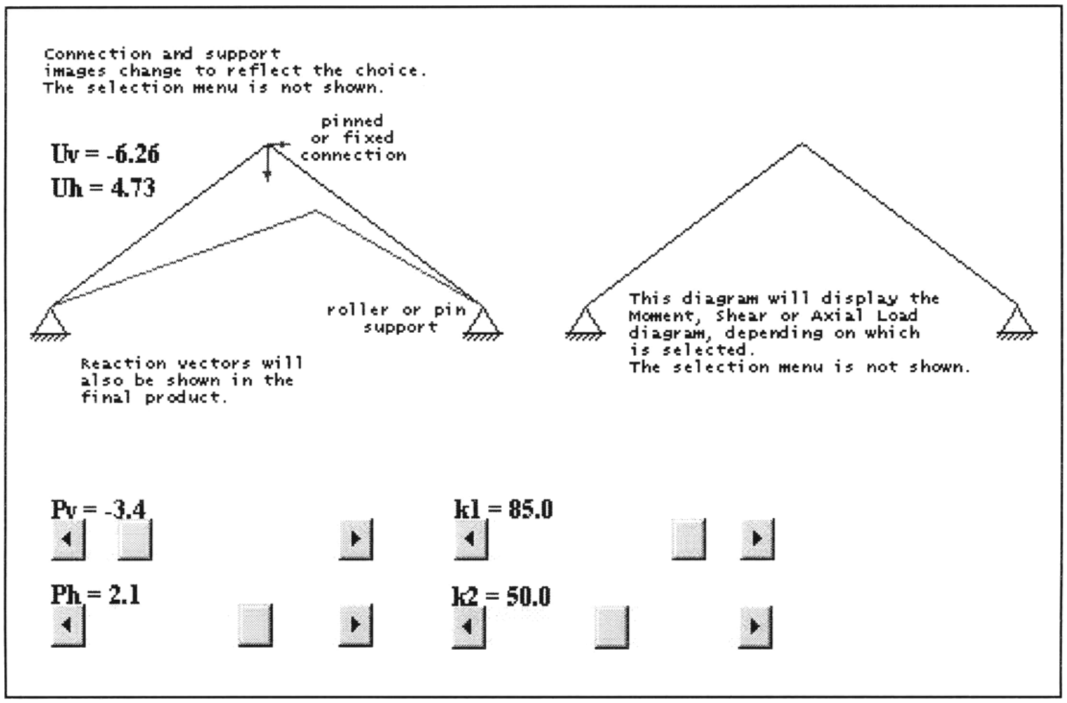


Figure 6.7 The Proposed Screen for the Dynamic Figure for "Is it a Frame or is it a Truss?"

Three types of variables are available – load magnitude, support conditions and member stiffnesses. The two variable loads are applied at the apex of the structure, with one being vertical and the other horizontal. The ability to vary the support conditions is where the potential of the learning hides. The possibility will be available to make the apex joint a pin or fixed and the right support a pin support or roller. The left support will remain unchanged.

Hence, there will be four support/connection arrangements that the student will be taken through with changing loads. Table 6.3 summaries this expected behavior and provides an indication of the order and process that would be used to teach this exercise. Accompanying this exploration with explanations, the student should learn the effect of the support conditions on member action and deformation. Hence, she or he will be introduced to the concept that there is the presence of truss action when there is an angled path provided for an applied load, and additionally the moment connections are negligible if the truss or angled frame is prevented from spreading. The opportunity to vary member stiffness can be utilized in a later lesson within exercise, allowing the student to observe its influence on the member force distribution. The conclusion for the student is that a frame will act as a truss whenever it can – it's more efficient!

Table 6.3 The Possible Connection/Support Configurations and their effect on the Structure Behavior

order	Apex Connection Type	Right Support Type	Predicted Response
1	Fixed	Roller	Large moment in members, as required to restrain the frame from spreading.
2	"	Pin	Close to wholly Truss action as the frame has been prevented from spreading by the lower supports, hence very small moment in members.
3	Pinned	Roller	Pure Truss Action – with no moment in members.
4	"	Pin	Collapse – Unstable!

This discussion could be extended further to include comparison of the angled frame above with a portal frame and arch, as well. Each structure could have the same purpose – to transfer the load at a certain location down to supports at other fixed locations, see Figure 6.8. The approach of each, however, is different; hence, the efficiency and behavior of the schemes could be compared.

Having concluded the presentation of the example module for *Momentous*, one final observation must be made: writing and developing the material to an appropriate level of knowledge, intelligence and speed is very difficult. This is surely a dilemma shared by many if not all educators.

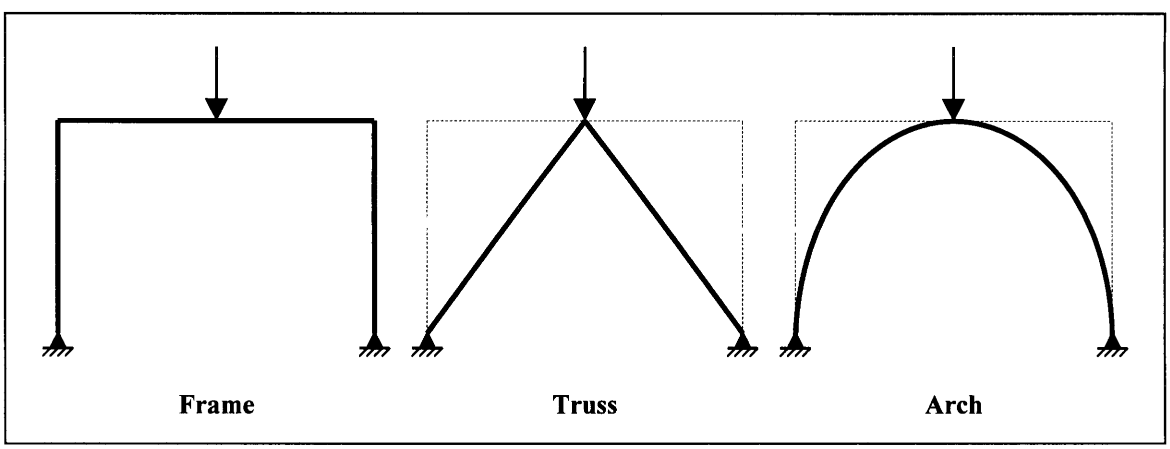


Figure 6.8 A Possible Framework for a Future Exercise to compare the Behavior and Efficiencies of a Frame, Truss and Arch

6.6 Assessment

As the project of developing *Momentous* has progressed, the importance of effective assessment has been seen increasingly; however the difficulty in achieving this has also been recognized. Hence, the lack of worthwhile assessment and feedback in the examples presented in the previous section. In this state, therefore, the examples fail a major requirement of both Theory One and the Tutorial Cycle. The role of this section is to propose some possible solutions to be developed and incorporated in the future.

Recalling from Section 3.2.1 on "Theory One", providing the student with an opportunity to reveal their depth of understanding allows the teacher to monitor their progress as well as encourage in them thoughtful practice and confidence. Various levels of assessment would appear to be required – at the local level of the student for continual feedback and motivation and then globally for the teacher to ensure progress and provide final grades. As will be seen shortly, if the soon to be proposed solution is applied, some overlap may be available between these two levels with the teacher having access to the results of the students self assessment exercises.

Currently, the only form of feedback that can be claimed by the example is the inclusion of basic questions to encourage involvement. One of the reasons why assessment is so difficult to achieve with *Momentous'* current form is the one-way environment of the computer that has been adopted. By using this format, how can a question be posed to the user without making the answer too easily accessible, yet still available? The student needs to be encouraged to think, not just press a button to get the answer.

The major problem has now been posed and the solution is seen with the introduction of intelligent agents. Algorithms can be developed to assess the students progress. The results can be collected from onscreen exercises using forms, and similar. Once submitted, the student's answers could not be changed, though the exercise may be revisited for review purposes only. To keep track of this, every user would have an account available with the program, allowing the additional bonus of the student being able to reenter the program exactly where they left off – the program effectively has a virtual memory.

Using the assessment made by the algorithms and agents, the program begins to become like a personal tutor effectively watching over the student accumulating information on them, monitoring their progress and making recommendations where appropriate. Remembering the note made in Section 3.2.2 on The Tutorial Cycle, the ideal learning environment is for a student to be one on one with a tutor. Using Intelligent Agents could perhaps bring *Momentous* one step closer to this. Their potential allows the student to be given extra exercises or "concentrations" when she or he is seen to need more help. The teacher can be advised, via email, of progress reports of the students and whenever they are seen as in need of human personal assistant, the teacher too can be alerted. Perhaps this should lessen the chance of students slipping through the cracks and falling behind. The approach will be in as gentle and unobtrusive manner as possible – it is not to be "Big Brother". Naturally, it requires some level, though not unreasonable, of commitment from the teacher. The product will hopefully be an intimate, supportive, learning environment.

Finally, finishing with a brief discussion on the techniques that will be used to develop the onscreen questions and quizzes. In Section 5.5 when considering Dynamic Figures, two roles were suggested for them – one for learning and one for assessing. The format of the Figures presented in Section 6.5 exploited only the first mode on learning, and whence, lies the opportunity for utilizing the second mode. Prof. Sakuta, a visiting professor to MIT, who completed the first Dynamic Figures for the project, developed a creative technique of writing "backwards" questions. The problems are approached from the opposite direction in which they were taught, essentially providing the answer and asking for the question to match it. For instance, providing the moment and shear force diagrams with the deflected shape, the student would be expected to find the loading and support conditions that would have produced this.

In Section 2.2, one of the poorest skills recognized of current new graduates is their ability to quickly sketch approximate bending moment and shear force diagrams, deflected shapes and reactions. The approach of Sakuta's described above should, therefore, assist in improving these skills as it forces the students to consider what the clues of the diagrams are and then apply them. Another method to encourage qualitative learning of this type is by providing a simple sketch pad on the screen which allows the student to quickly plot the diagrams by marking the critical expected features.

All of these assessment exercises are foreseen as being incorporated into the *Slide Shows* and *Interactive Exercise* by placing them at the end of the total module or lesson, if there is more than one in an *Exercise*. Example questions to be posed for the *Slide Shows* could include multiple choice or simple text problems with practical images. Images could also be included that require simple input on them, i.e. for the "Load Paths" module a structure could be displayed on the screen that requires the load path arrows to be drawn. Hot spots could be created in the correct regions to sense if the students answers are valid.

When posing and developing any of the questions, one encouraging aspect for the author was found in the book by Brown et al "The Art of Problem Solving"[9]: the newer a person is to a topic then often the more informative and enlightening the problems they create. Thus, hopefully, the author with her short experience is an acceptable person to handle the task of developing assessment problems for the program, with tutelage of course.

In conclusion, the author has found herself becoming more ambitious as she has delved deeper into the project, hence the acceptance of such ideas as the Intelligent Agents. Her main goal with the development of assessment, however, is to ensure the student is thinking and not simply having information passed on them in the hopes that they will just know when and how to apply it.

6.7 Conclusion

The current status of the learning environment, *Momentous*, has now been presented to the reader and can be seen to be very much a work in progress. Many exciting opportunities and challenges have been revealed to the Author, which she anticipates exploring as she continues to work on the project's development.

Solving the problem of including effective assessment appears to be the greatest hurdle to be overcome in order to achieve total interactivity for the user. At a more basic level, as can be seen from examining the examples in Section 6.5, a major difficulty in creating them is keeping the level of text down. Hence, the potential of audio is excellent – allowing, ideally, the screen text to be optimized with useful and interesting supplementary information transferred effectively through sound.

A great deal of work is still to be done, but the trends have now been set to prove that the approach of *Momentous* is definitely worthwhile.

Chapter 7.

CONCLUSION

The dominance of computers in our future lives must be recognized, particularly in regards to the potential they may provide education. By not ignoring this fact and finding themselves left behind at the starting posts, educators can rise to the occasion and exploit these available opportunities to produce worthwhile and cutting edge learning tools. The early developments of the teaching package, *Momentous*, as discussed in this thesis, have attempted to achieve such a goal, meeting the new paradigms emerging in Structural Engineering Education and the role of the Computer.

The program's aim is to develop innovation in teaching through an integrated learning environment for understanding structural behavior. Its process is to instill in undergraduate students a qualitative and questioning nature, and encouraging their response to understanding structures to approach reflex action.

From the work of Chapter 6 and through the justification and support of the earlier chapters, the exercise of developing *Momentous* has been proven viable and worthy. Much work is still required on the package, however, to ensure its successful progress and future implementation. Beyond just the need to create a complete catalogue of *Slide Shows* and *Interactive Exercises,* efforts are also required in other areas. An effective assessment scheme through intelligent agents, as introduced in Section 6.6 is to be built to ensure a fully interactive, intimate experience for the user. Other challenges include integrating the package's elements effectively to achieve the appropriate balance of assumed user intelligence, interest and new challenging material. A continual feeling of challenge and a sense of direct engagement are of course strong desires for the user. The dilemma of solving the position of the analysis methods in Structural Engineering Education as discussed in Section 2.5, also needs to be resolved.

Finally, one other extremely important aspect to be included in future work on *Momentous,* is the testing of the package on novices from the target audience. Such investigations are necessary to confirm and demonstrate the program's effectiveness and satisfaction of the desired goals as set out in Chapter 5.

With these recommended future developments, the potential has now been seen to expand the work into a worthwhile Doctorate of Philosophy thesis of sufficient intellectual rigor. Through the generation of this higher level thesis, it is anticipated that a final and marketable project may be produced.

Before being fully beguiled by the possible virtues of virtual tutors and the like, the author will attempt to display some rationale during her future work. She fully recognizes that focus must remain on the task and not the tool. A wonderful quote was found in Norman's Book [16], "Things that make Us Smart", as follows,

"Science Finds,
Industry Applies,
Man Conforms.
Motto of the 1933 Chicago World's Fair

People Propose,
Science Studies,
Technology Conforms.
A much improved motto for the twenty-first century"

This raises a very important issue as emphasis continues to be placed on maintaining the user's interest to enable learning through the best possible mode. Technology must be molded and compromised to Man's needs and not vice versa. Ironically, the direction computer development is taking indicates that it is actually making this goal easier to accomplish.

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Appendix A.

COURSE CURRICULUM

1. Introduction

a) Types of Loads – both cause and action e.g.:
   - dead load, live load, thermal, snow, wind, support movement, etc.
   - point load, uniformly distributed load, moment, patch loading, etc.
   - static, moving, pattern, dynamic.

b) Nature of Construction Materials and Structural Components
   - Stress-strain behavior of materials (strength, elasticity, ductility)
     Stress and deformation relationships with Hooke's law, including the variation in this behavior between materials, e.g.:
       Linear-ductile material (steel)
       Linear-brittle material (concrete, carbon and glass fibers)
   - Axial Tension Components – only examples/types required with visual examples and applications, e.g.:
     ropes, chains, cables, rods.
   - Axial Compression Components, e.g.:
     struts and columns, ideally use stone, concrete.
   - Moment Resisting Components, e.g.:
     beam, also with additional tension and compression forces.
   - Shear Resisting Components, e.g.:
     beam, shear beams and walls.
   - Support Condition Examples, e.g.:
     pins, fixed/moment connections, springs (axial and rotational) including where and when they are used and modeled.
   - Prestressing – axial and bending – merely discussed conceptually with simple diagrams

b) cont... Nature of Construction Materials and Structural Components

- Reinforced Composites – maintains a practical aspect to the teaching material, could perhaps be introduced above with the section on stress-strain, e.g.:
  reinforced concrete,
  fiber reinforced composites

c) Types of Structural Systems
Provides an introduction to trusses, frames, shells, etc., as it briefly displays where the components and support conditions mentioned in the previous section are used.

d) Structural Responses, i.e. deflections, curvatures, stresses, strains, reactions

- Structural behavior measures – compression, tension, bending, shear, torsion, etc.
- Structural failure modes
  Strength
  Stability
- Performance requirements (strength, stiffness, etc)
  including an introduction to typical design criteria, i.e. safety, economy, architectural and services requirements.
- Structural analysis related to structural response (how to compute or to estimate the response of actual or proposed structures)
- Structural design related to structural response (how to synthesize a structure with the desired response), i.e. Motion based design

2. Basic Tools for Determining Structural Behavior

- Structural modeling and idealization – free body diagrams
- Statics and Equilibrium
- Compatibility of deformations –
  provides an excellent prelude to teaching indeterminate structures
- Constitutive relations
- Linear and nonlinear systems –
  discussed conceptually only with examples and applications
- Principle of superposition (linear systems)
- Statically determinacy and indeterminacy ; degrees of redundancy –
  including the notion of continuity, of relative stiffness, and redundancy
- Stability –
  covering the difference between a mechanism and a stable structure, and for beams, frames, and 3D forms.
- Energy principles (internal and external work)

3. Review of Structural Member Behavior

- Member cross-sectional properties
  relating the effect of area and moment of inertia to a component's performance, allowing conceptual optimization of member behavior
- Behavior of members under axial loading,
  including extension, buckling and possibly a conceptual introduction to the P-Δ effect
- Behavior of members under transverse loading
  Basic Elastic Bending Theory…
  Shear
  Moment
  Moment-curvature; moment-area relations

4. Beams

a) Statically determinate beams
  - Shear and bending moment diagrams
  - Deformations and displacements
  - Design of beams
  - Design for moving loads – influence lines

b) Statically indeterminate beams (e.g. fixed end, multispan, etc.)
  - Superposition
  - Design
    Static loads
    Moving loads
  - Limit states; nonlinear (ductile) behavior, i.e. plastic hinges
  - Support movements

c) Cable-stayed bridges

5. Plane Frames

a) Statically determinate frames
  - Axial, shear and bending moment diagrams
  - Ideal truss – a special type of frame
    Arrangement of members – why do they have no bending?
    Locations of loads
  - Deflections and rotations

b) Statically indeterminate frames
  - Approximate methods
    Deformations and curvatures; inflection points
    Moment and shear diagrams
    Truss assumption – momentless frames
    Validity of truss assumptions
  - Superposition
    Simultaneous equations
  - Support movement

c) Different Types of Frames
   - Portal Frames
   - Gable Frames
   - Segmental Frames

d) Arches – yet another special type of frame
   - Three Hinged arches
   - Two hinged arches
   - Fixed arches

     Approximate methods of analysis

     Superposition

6. Multibay frames

a) One story rectangular building frames
   - Approximate analysis
   - Exact analysis – superposition
   - Analysis for moving and live loads
   - Design

b) Bridges
   - Multispan rectangular bridges
   - Multispan arch bridges

7. Multistory frames

a) Multistory building frames

b) Vierendeel trusses

8. Multibay, multistory frames

a) Effects of column stiffness on behavior

b) Effects of beam stiffness on behavior

c) Bracing in multistory building frames

d) Shear walls in multistory building frames

e) Design of multistory building frames

f) Nonlinear (ductile) behavior of frames

   Links well with dynamics, with it ability to absorb energy

9. Planar Grids

10. Dynamic Loads and responses

a) Wind loads

b) Earthquake loads

c) Simple dynamic (1 DOF) models
   Natural periods (including their simple estimation for a building)
   Damping
   Free vibration
   Forced vibration

d) Design for dynamic effects

11. Cables/Nonlinear Form-Dependant Structures

12. Shells/Plates

- Including Yield Line theory

Appendix B.

WORKED EXAMPLES

B.1 Slide Show – "Seeing Load Paths"

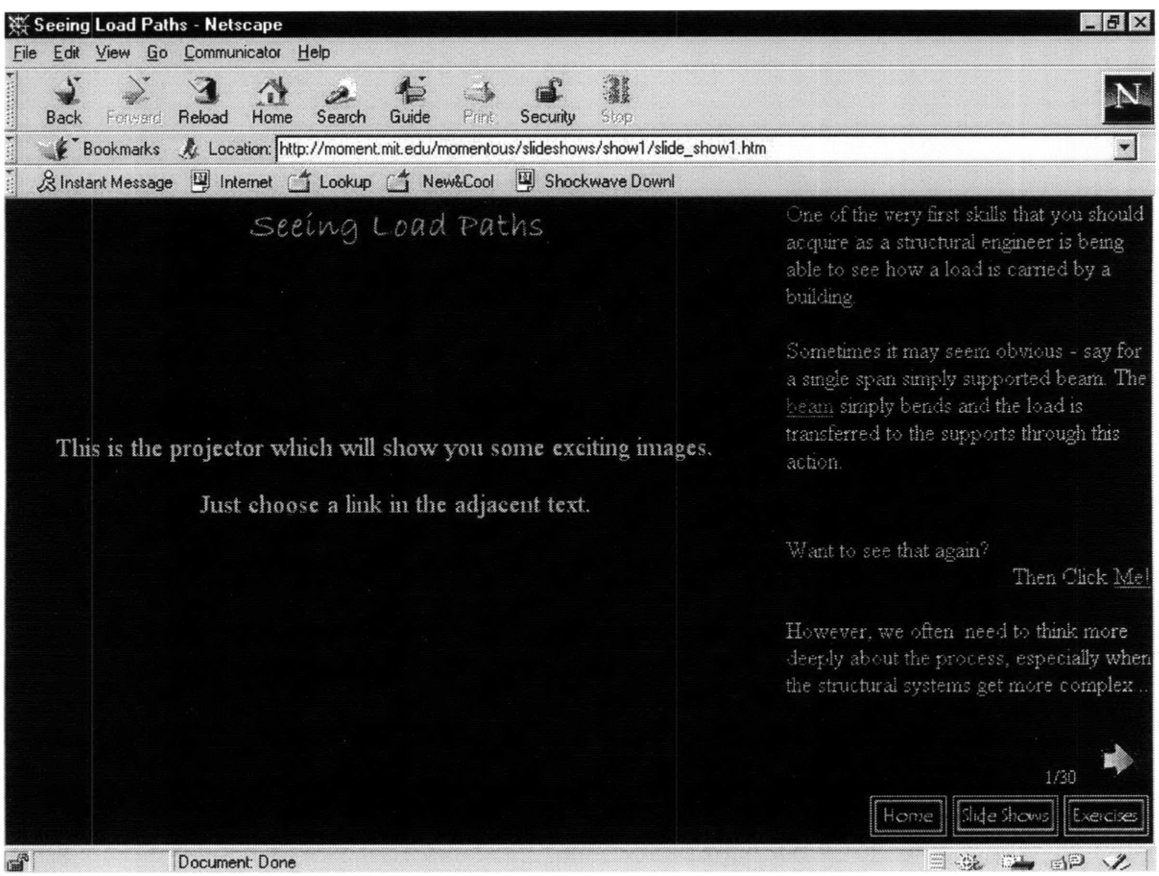

Figure B.1 Screen 1

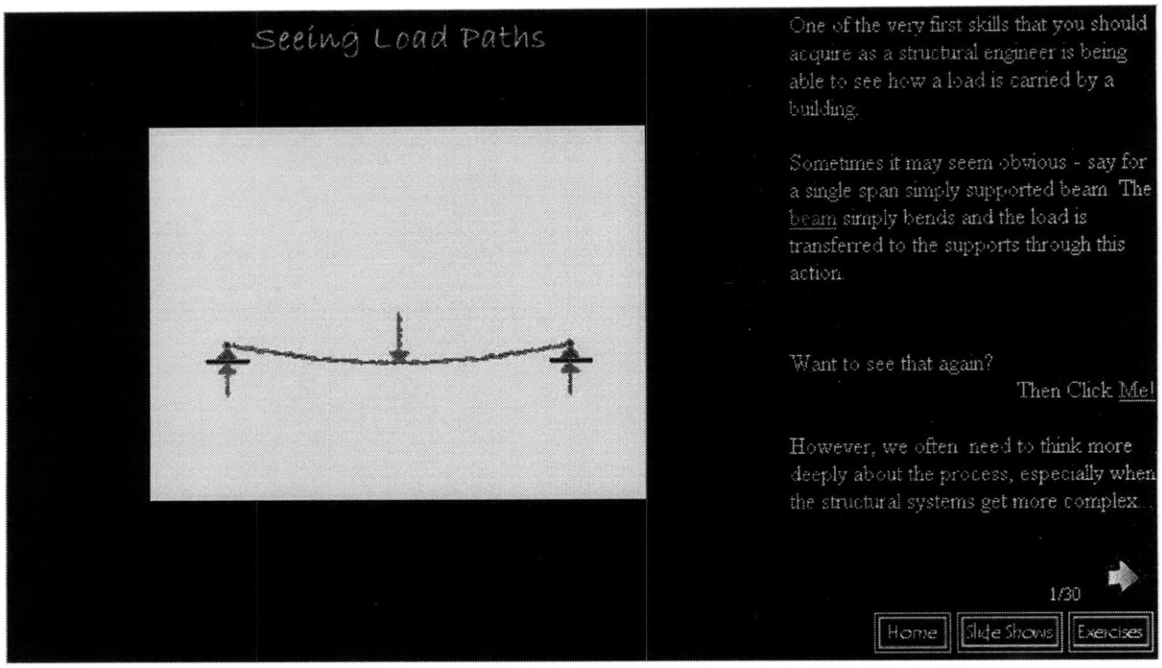

Figure B.2 Screen 1 with animated figure selected

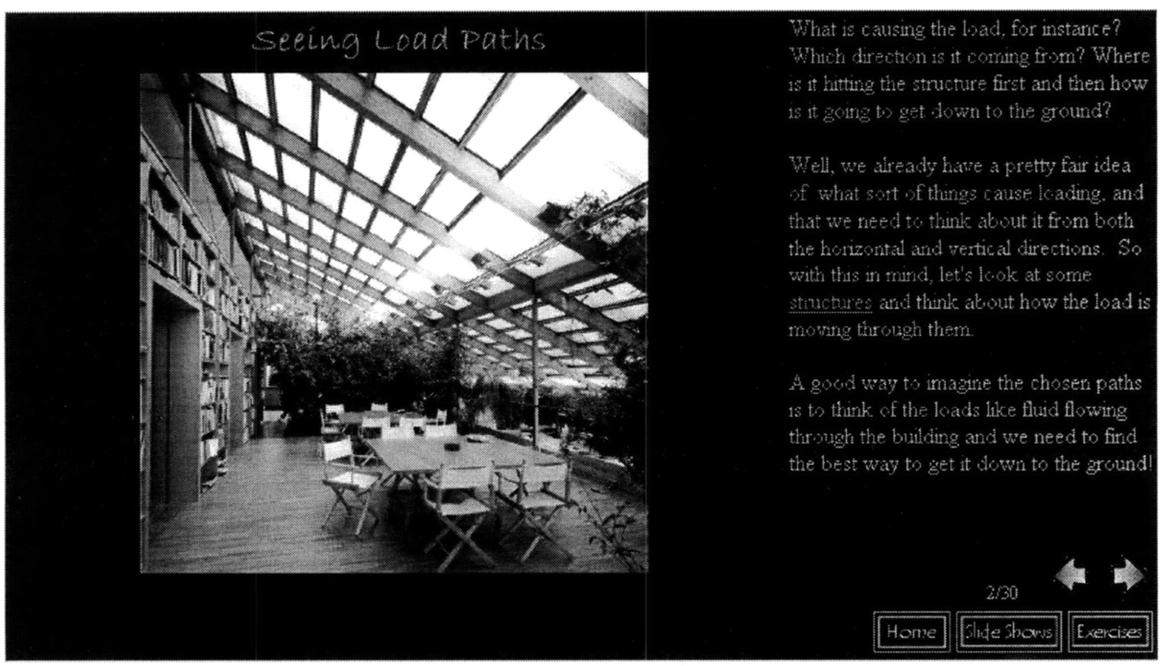

Figure B.3 Screen 2 with the first structure to be examined (image Ref [19])

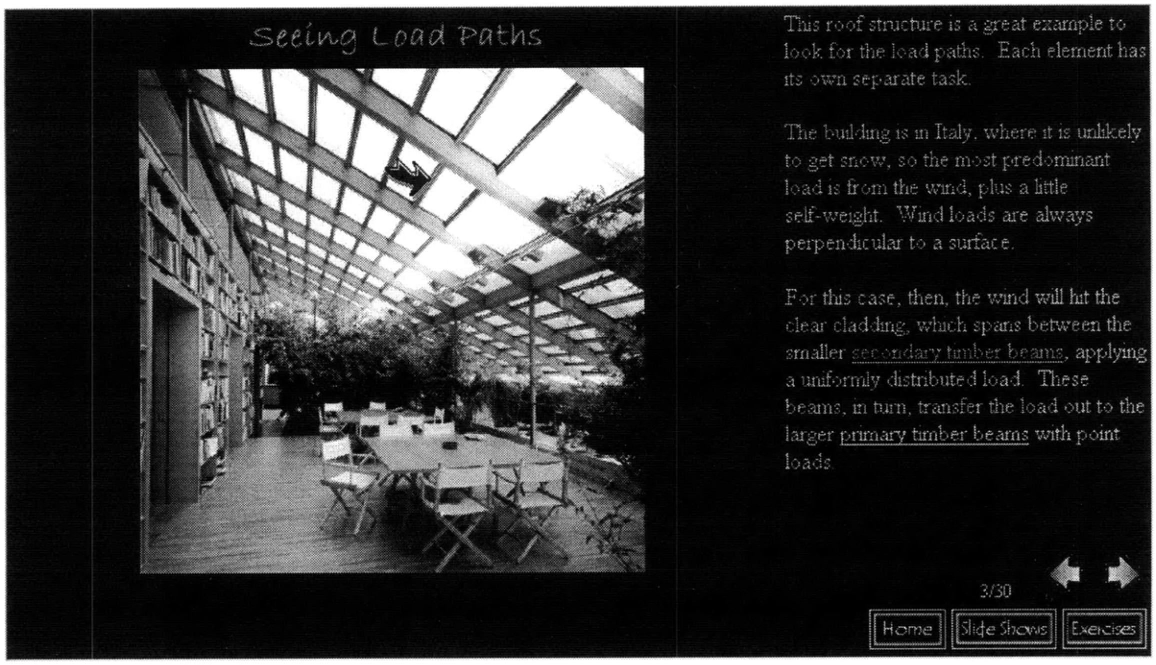

Figure B.4 Screen 3 with the secondary beams indicated

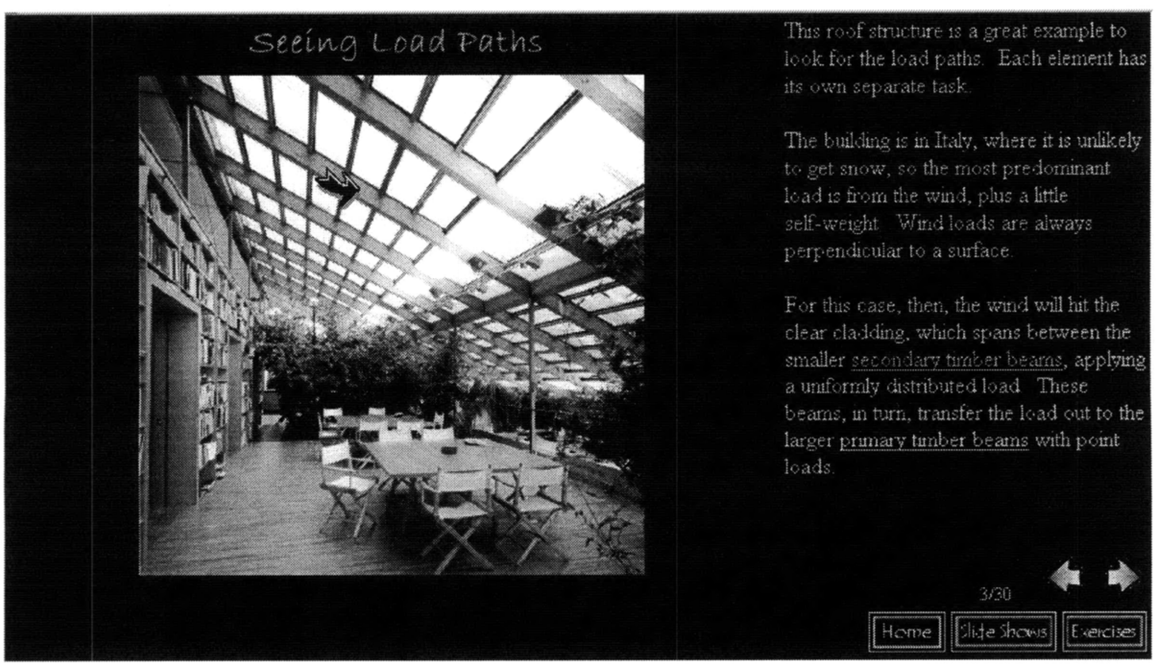

Figure B.5 Screen 3 with the primary beams indicated

Figure B.6 Screen 4 with the different types of primary beams indicated

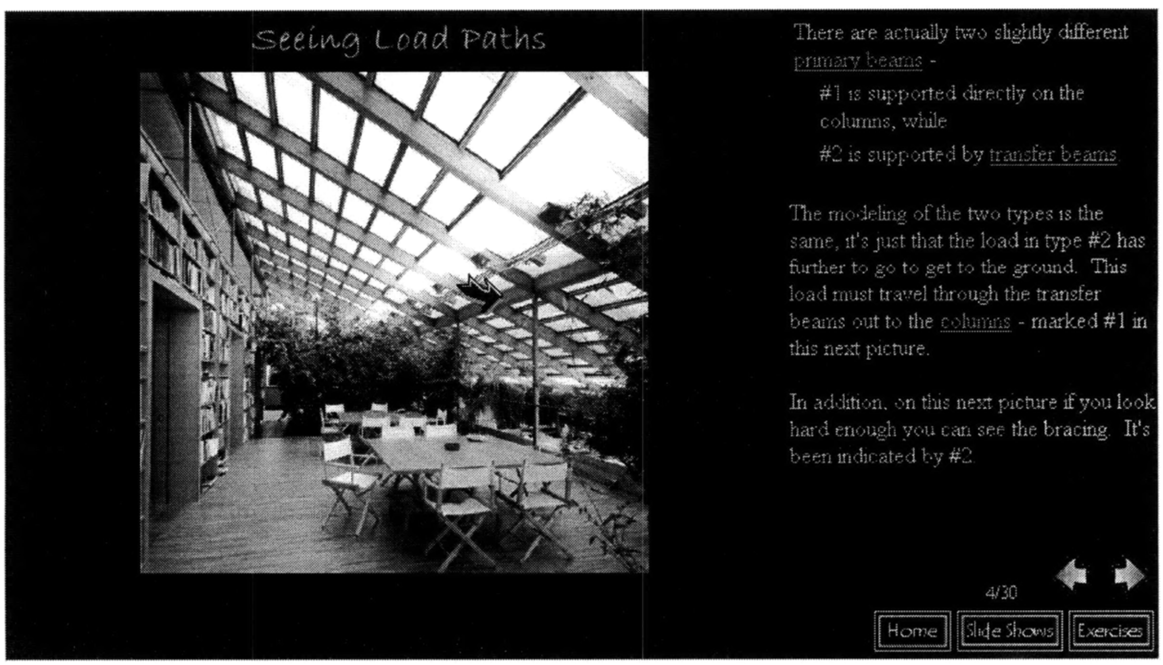

Figure B.7 Screen 4 with the transfer beam marked

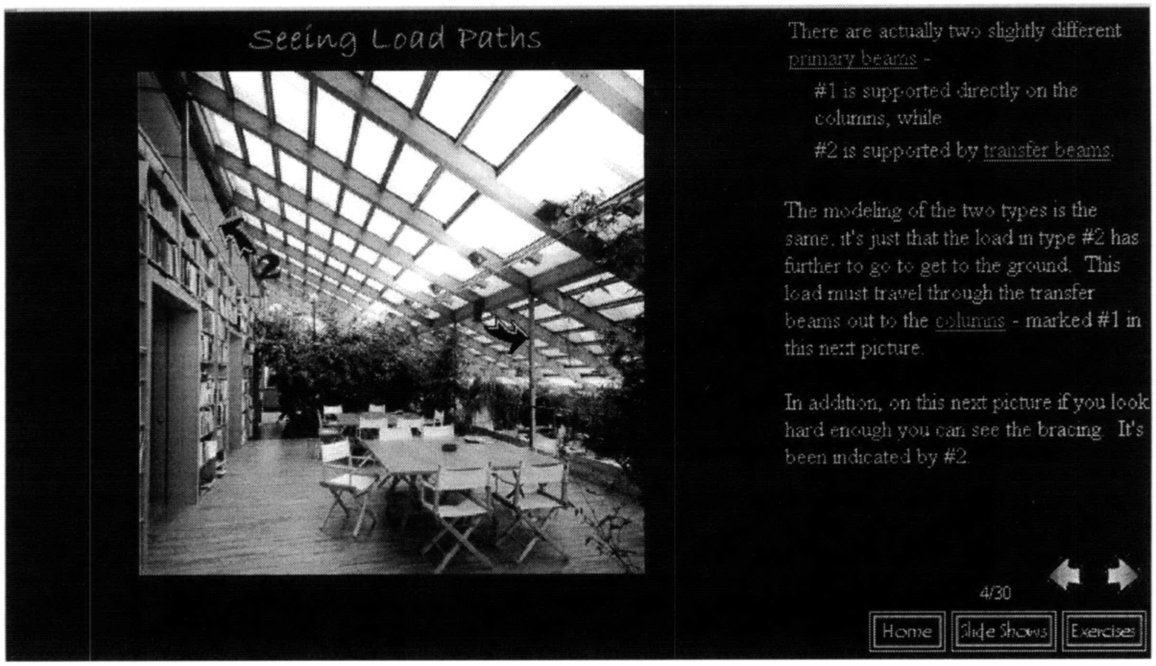

Figure B.8 Screen 4 with the columns and bracing marked

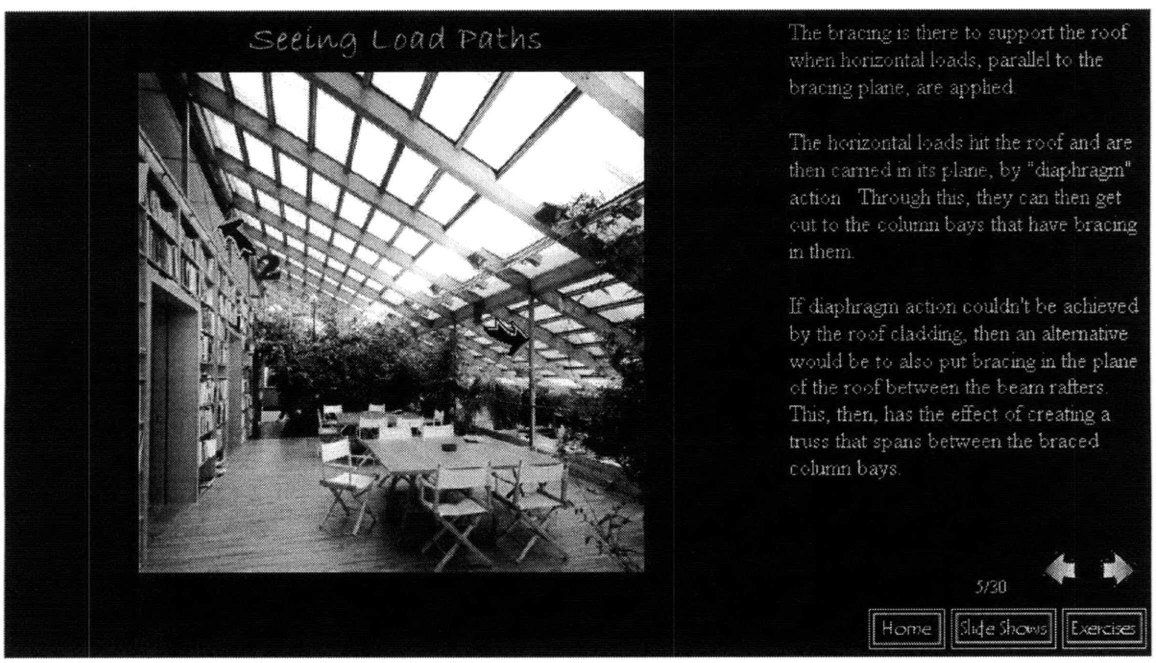

Figure B.9 Screen 5 discussing the role of bracing

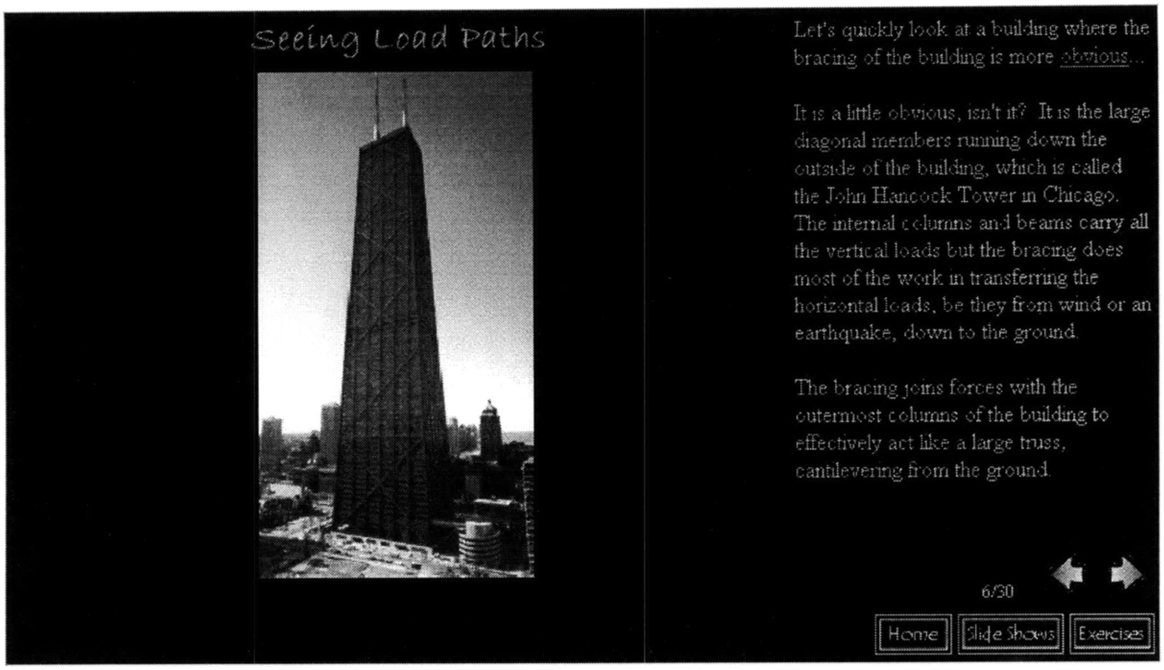

Figure B.10 Screen 6 further discussing bracing with a new example (image Ref [12])

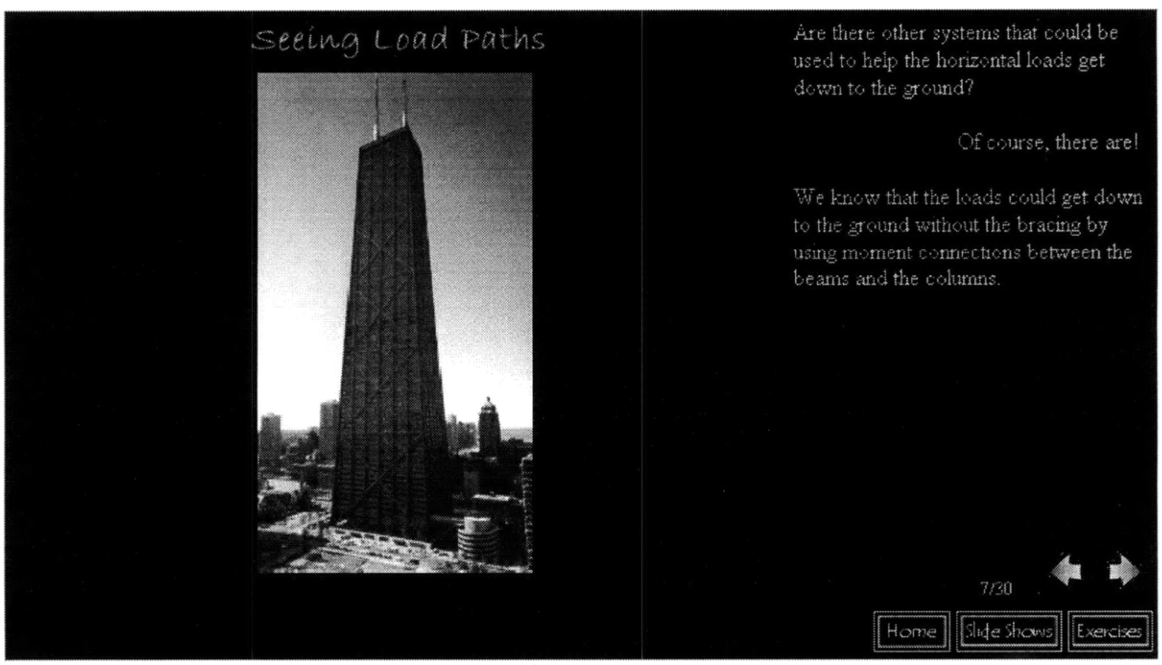

Figure B.11 Screen 7

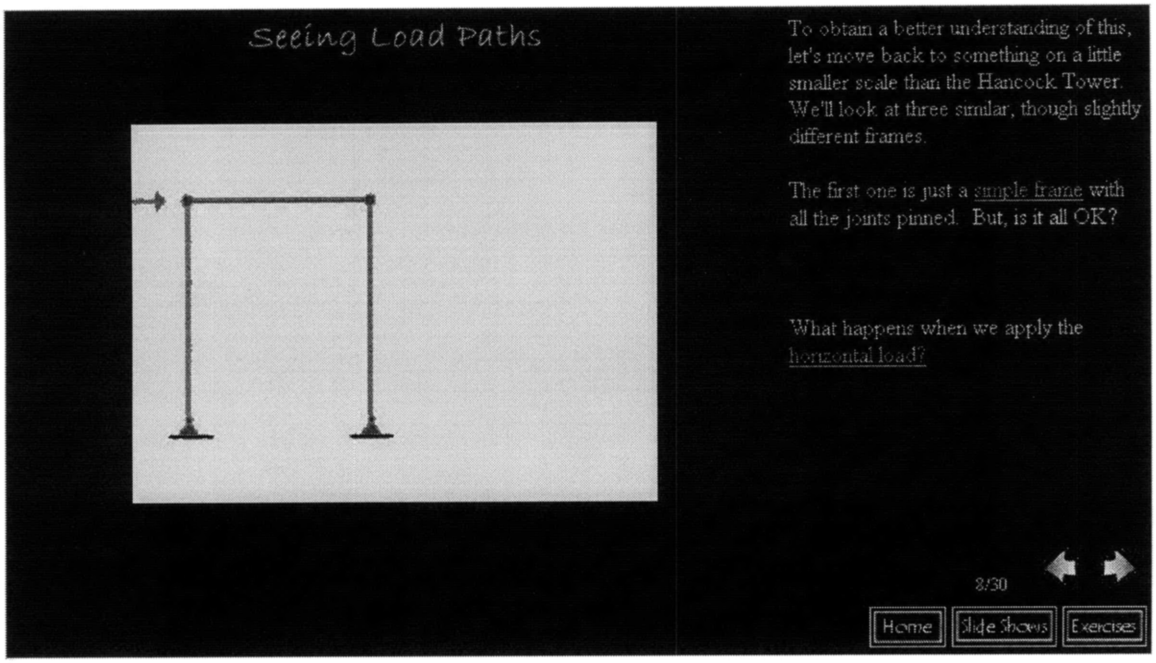

Figure B.12 Screen 8 beginning a discussion on stability with an animated image of an unstable frame

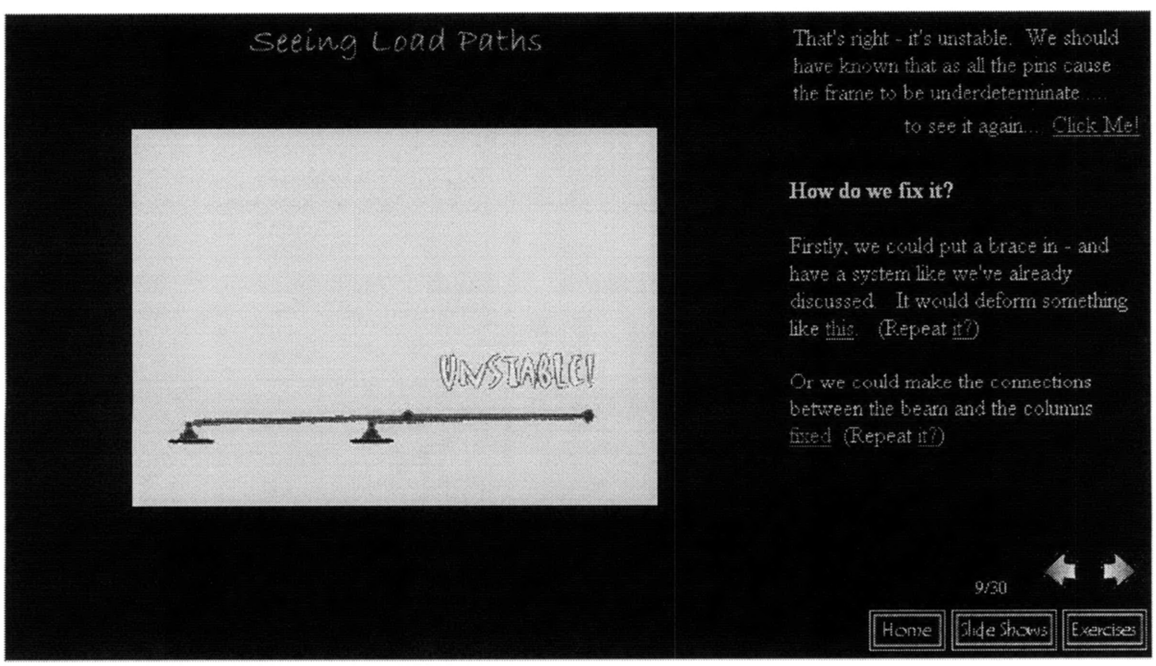

Figure B.13 Screen 9 continues with two other animated images that offer solutions to provide stability

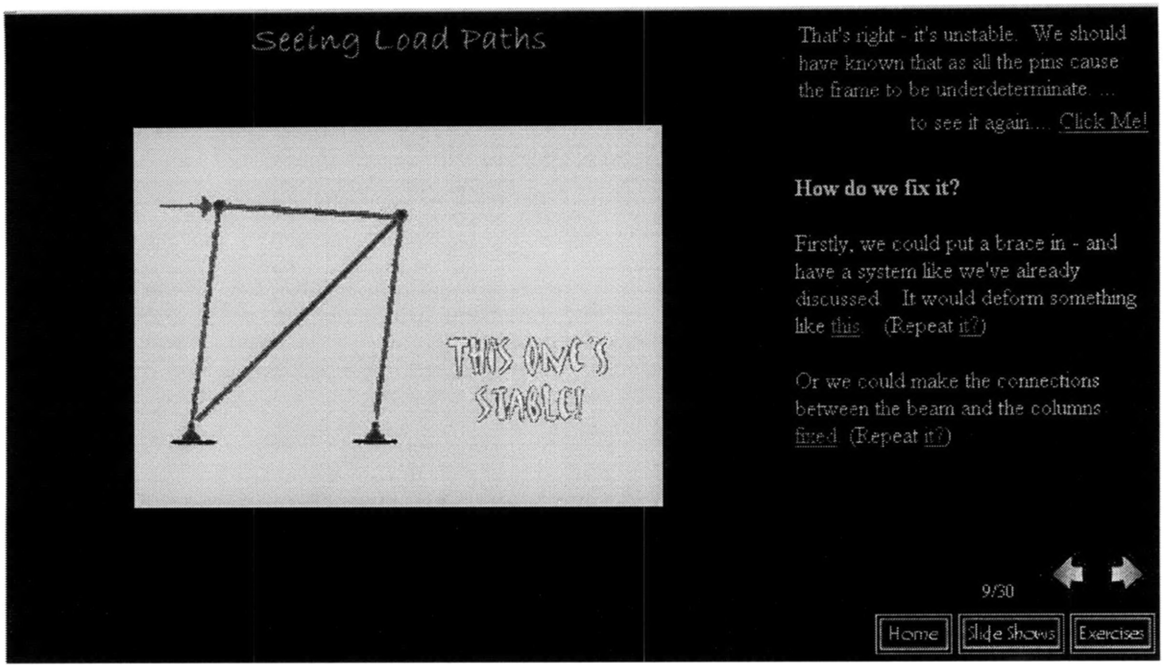

Figure B.14 Screen 9 with the first solution of a braced frame

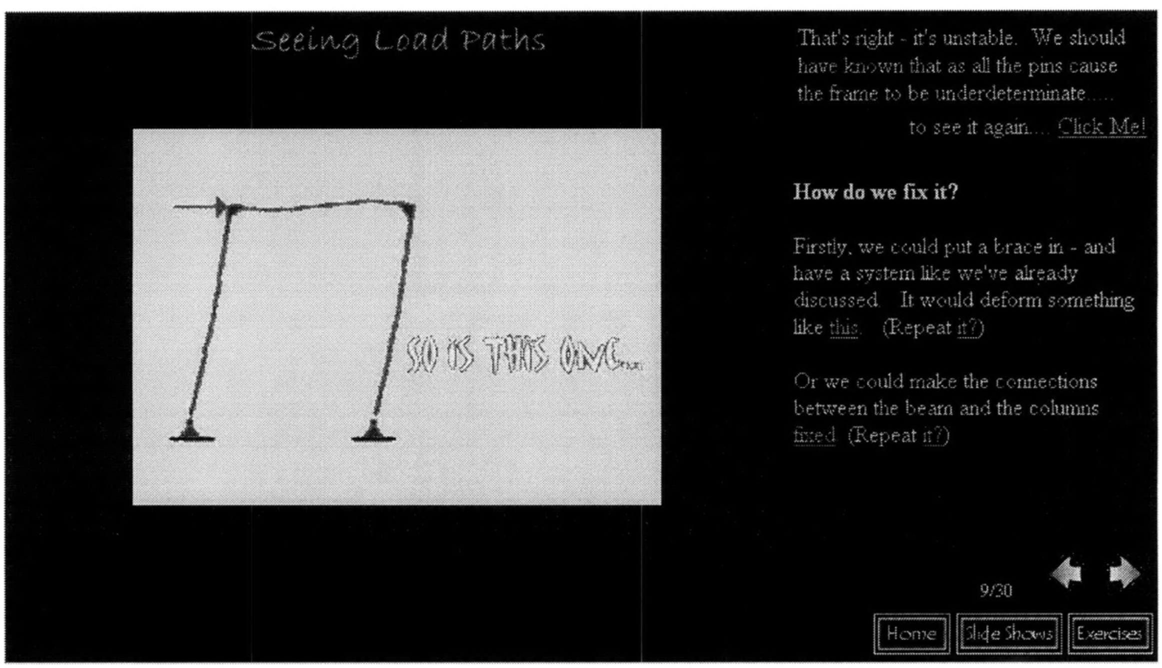

Figure B.15 Screen 9 with the second solution of a fixed frame

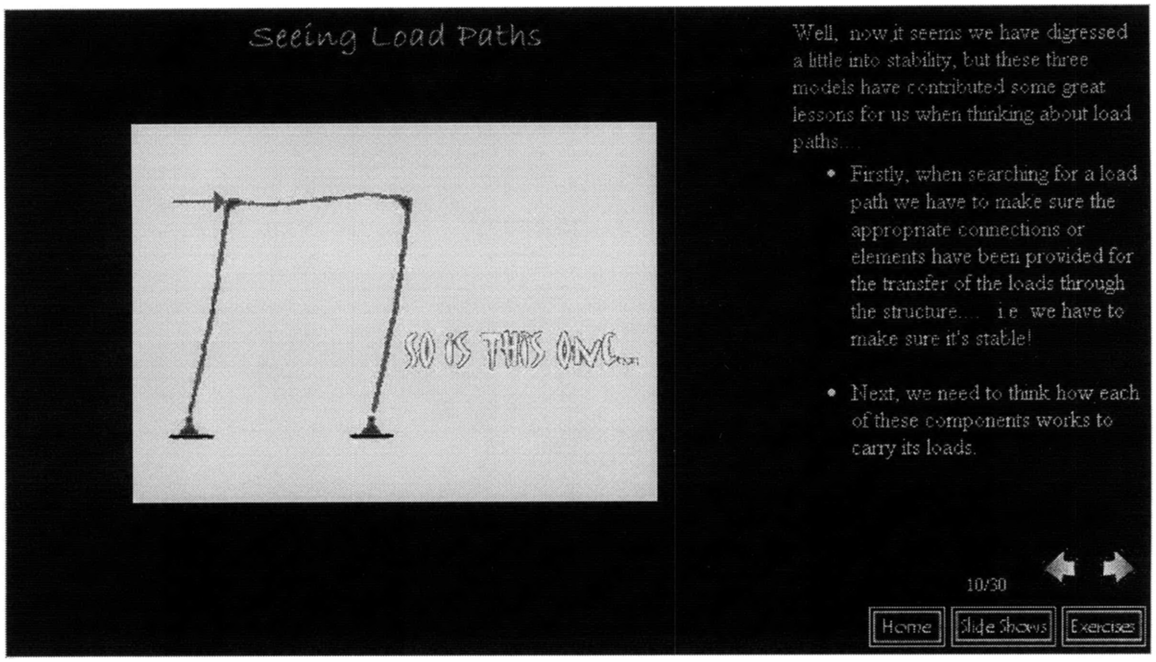

Figure B.16 Screen 10 summarizes on lessons have been acquired from this brief investigation into stability

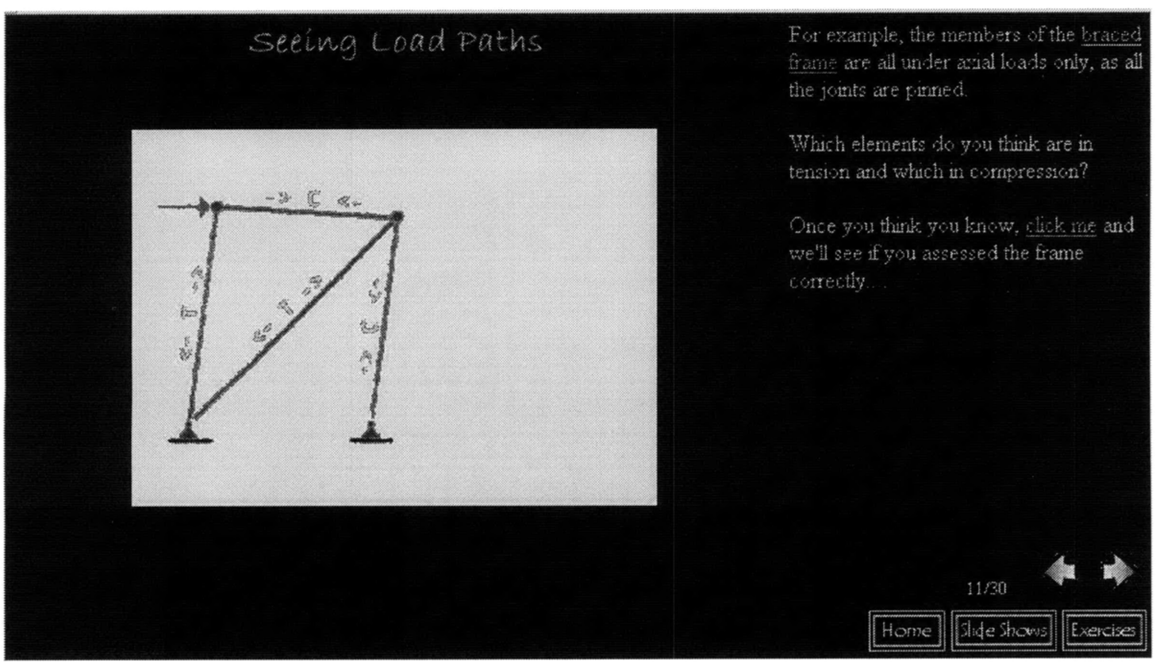

Figure B.17 Screen 11 now begins to consider what force actions are acting in the braced frame example

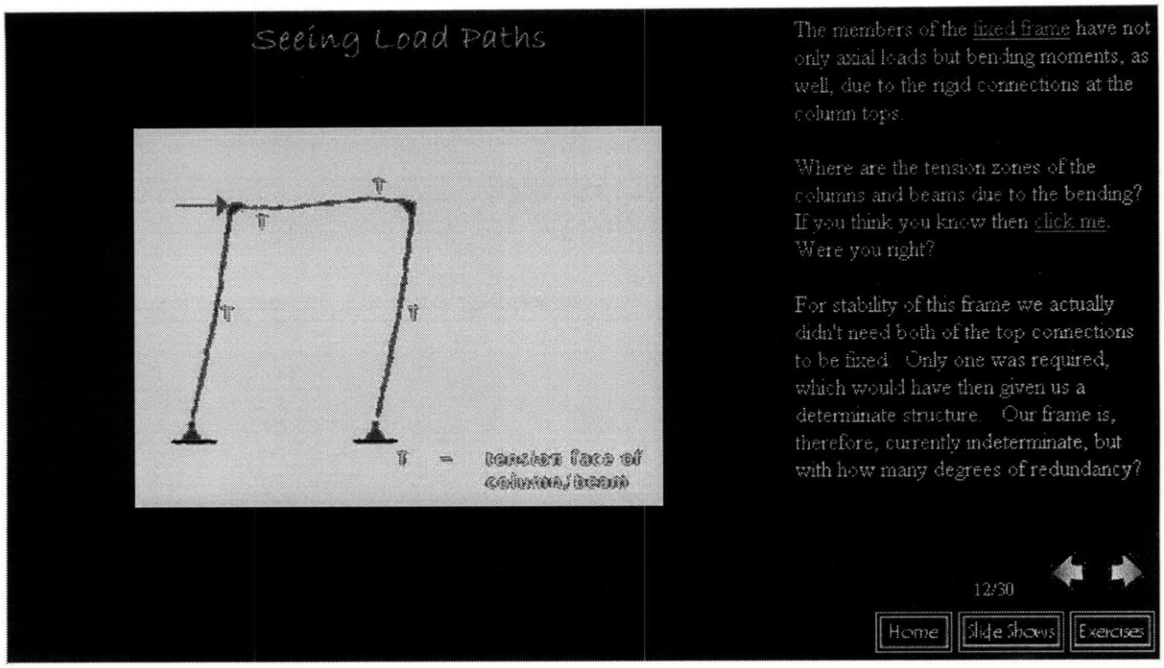

Figure B.18 Screen 12 considers the stress actions acting in the fixed frame

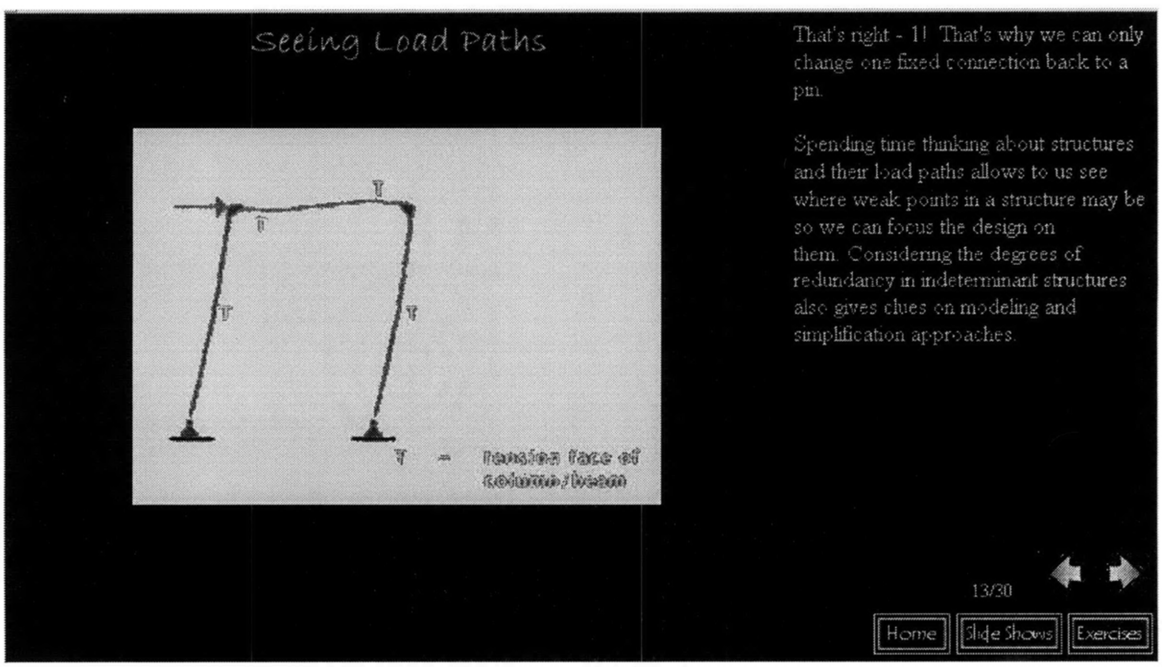

Figure B.19 Screen 13 briefly discusses the indeterminacy of the fixed frame

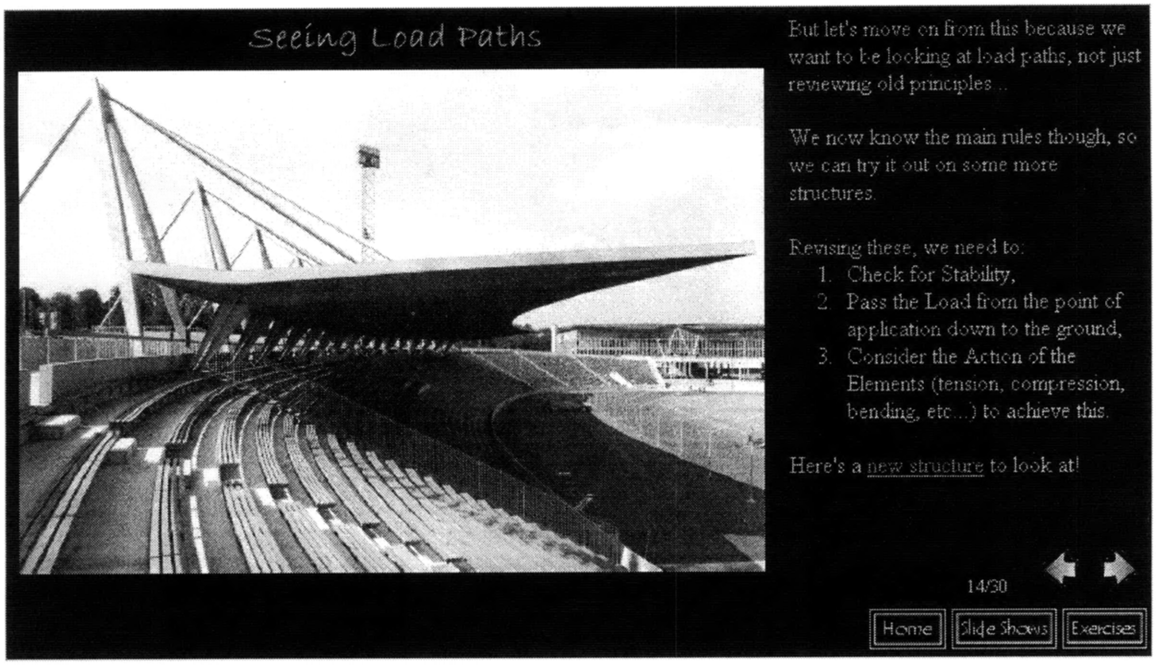

Figure B.20 Screen 14 reviews the new rules learnt for seeing Load Paths, before introducing a new, slightly more complicated structure (image Ref [17])

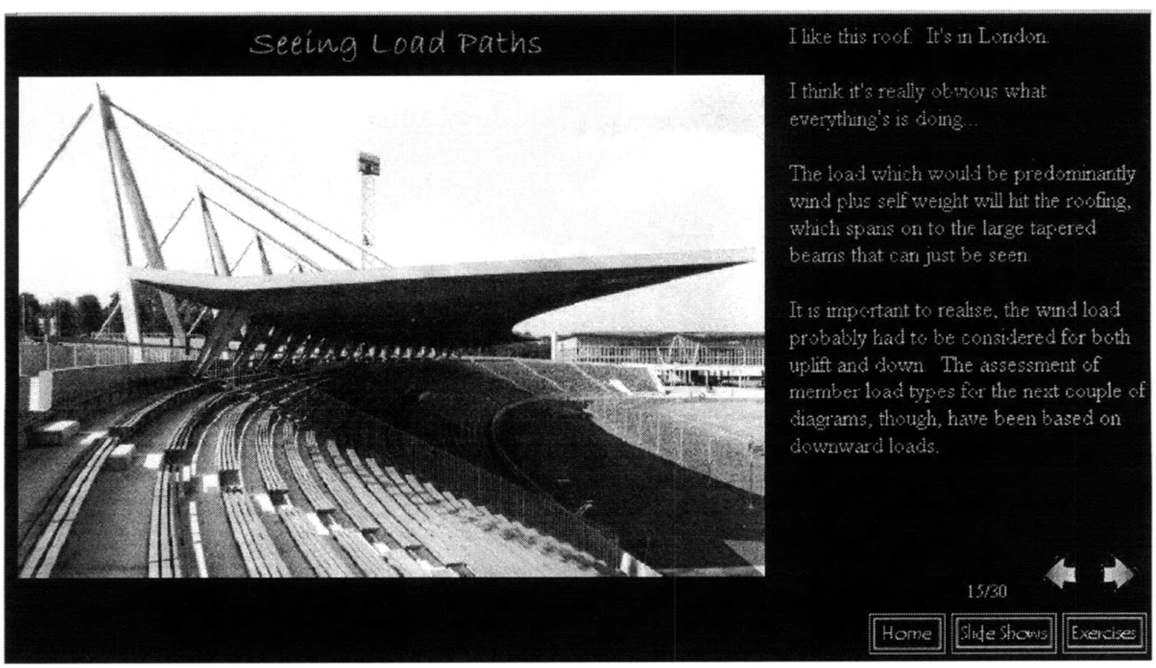

Figure B.21 Screen 15 provides further preliminary discussion on the structure, including the expected loading conditions and those assumed in the future slides

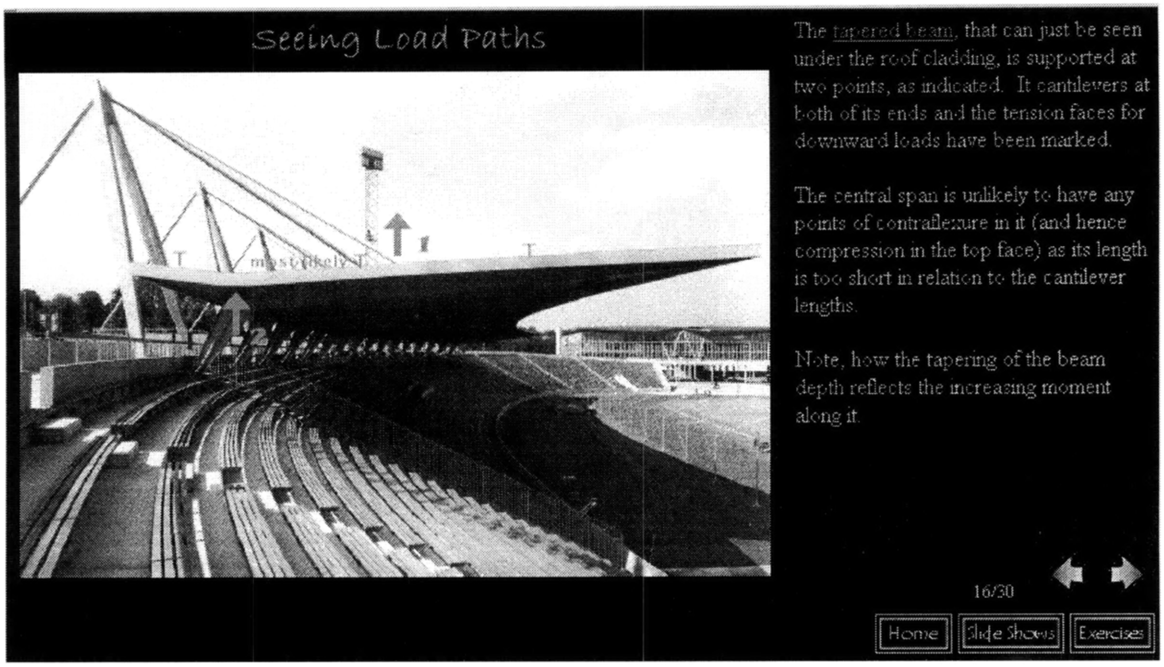

Figure B.22 Screen 16 commences the load path discussion, with the forces marked

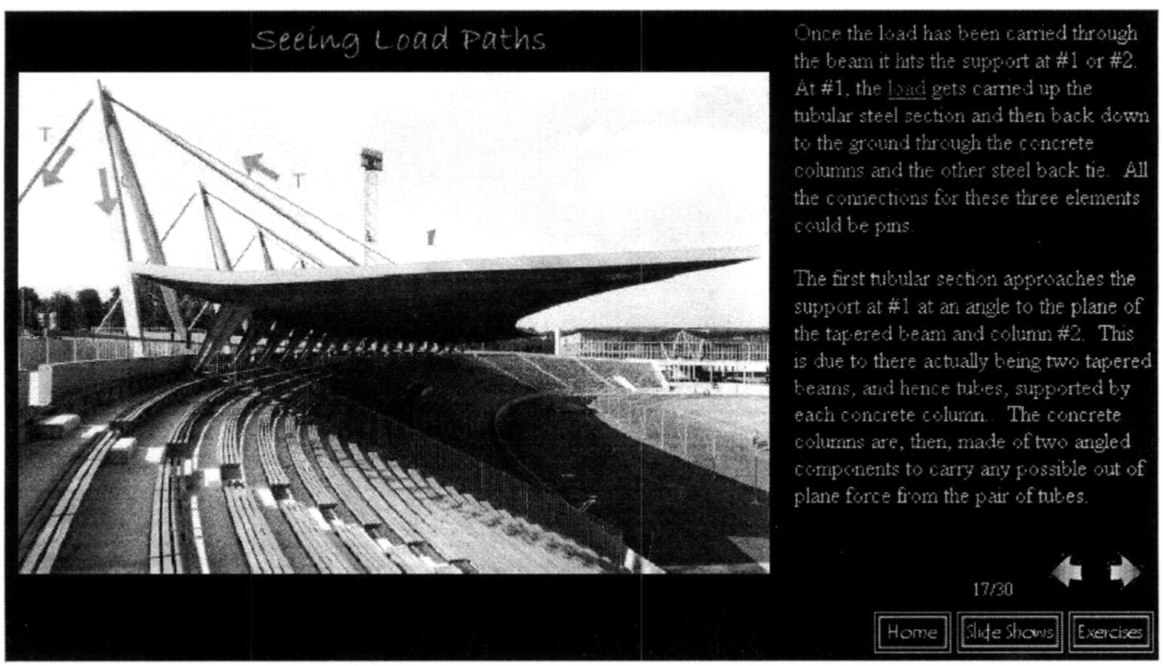

Figure B.23 Screen 17 continues the load path discussion

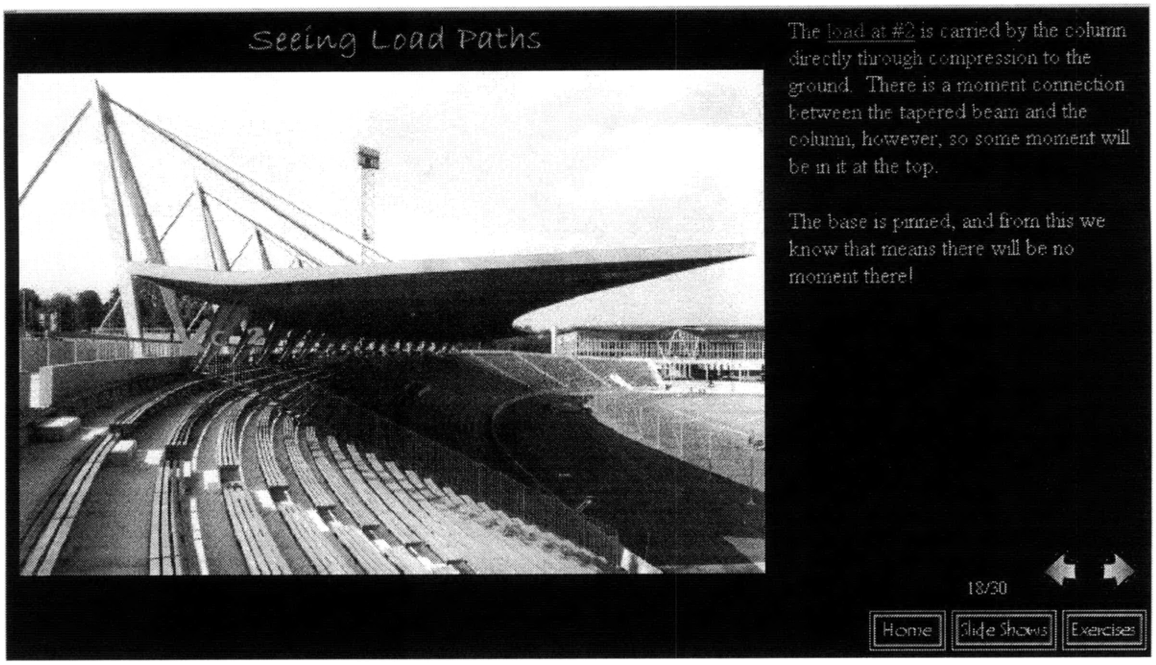

Figure B.24 Screen 18 completes the path of the load through to the column

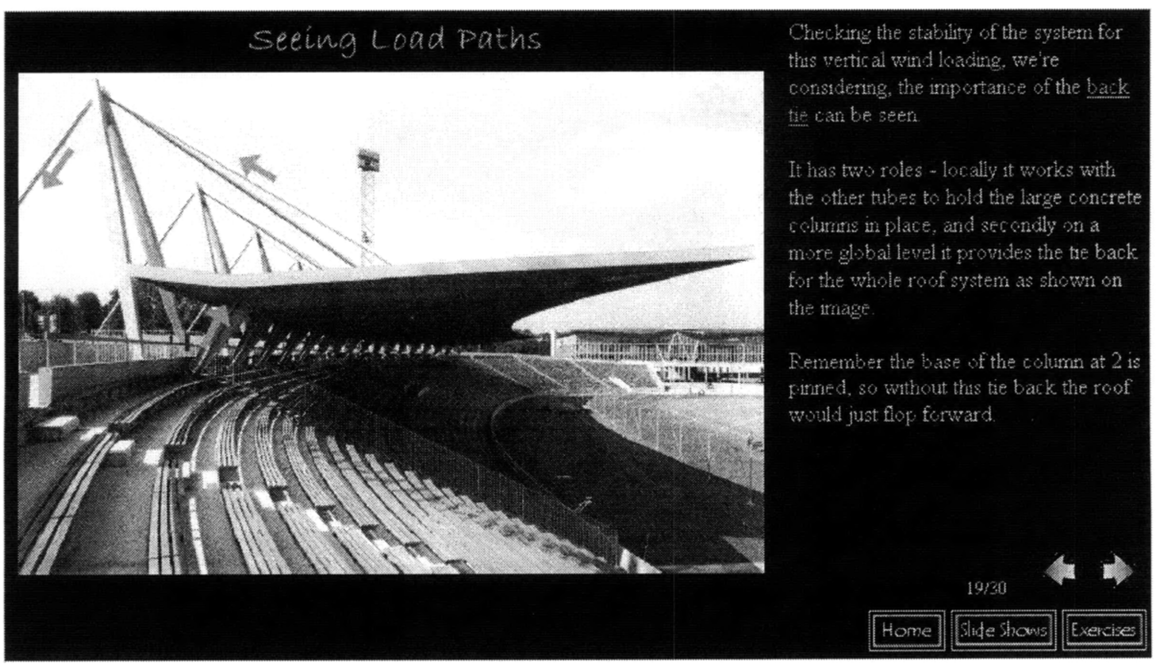

Figure B.25 Screen 19 discusses the importance of the back diagonal tie

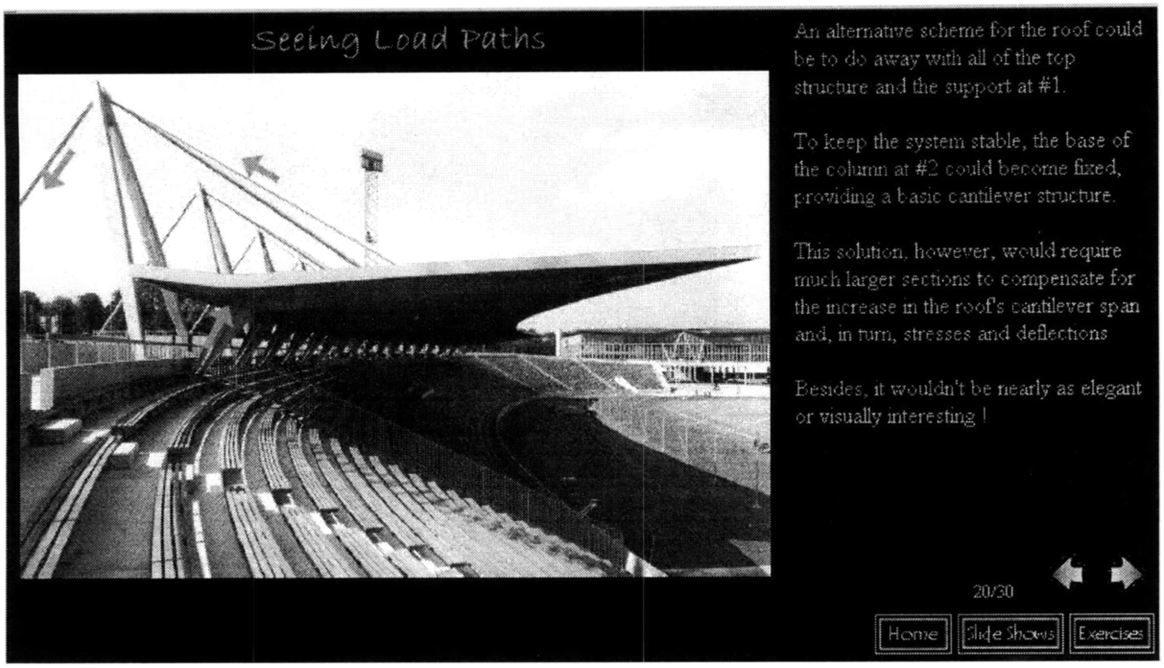

Figure B.26   Screen 20 considers an alternative scheme for the roof system

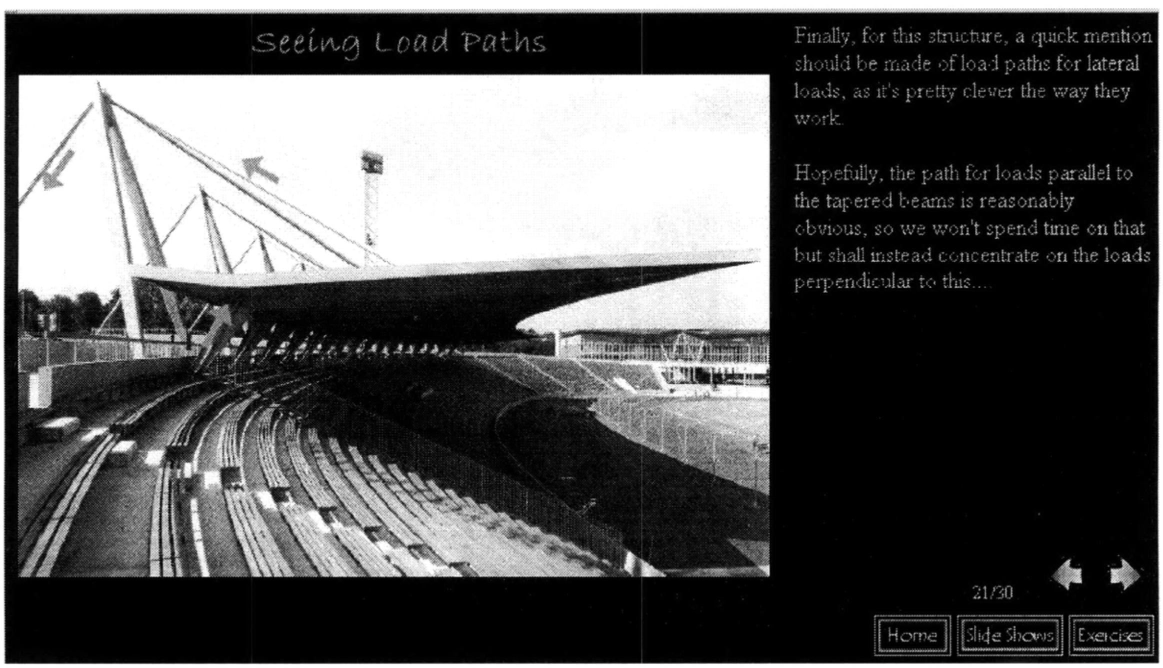

Figure B.27   Screen 21 looks at the systems stability under lateral loads

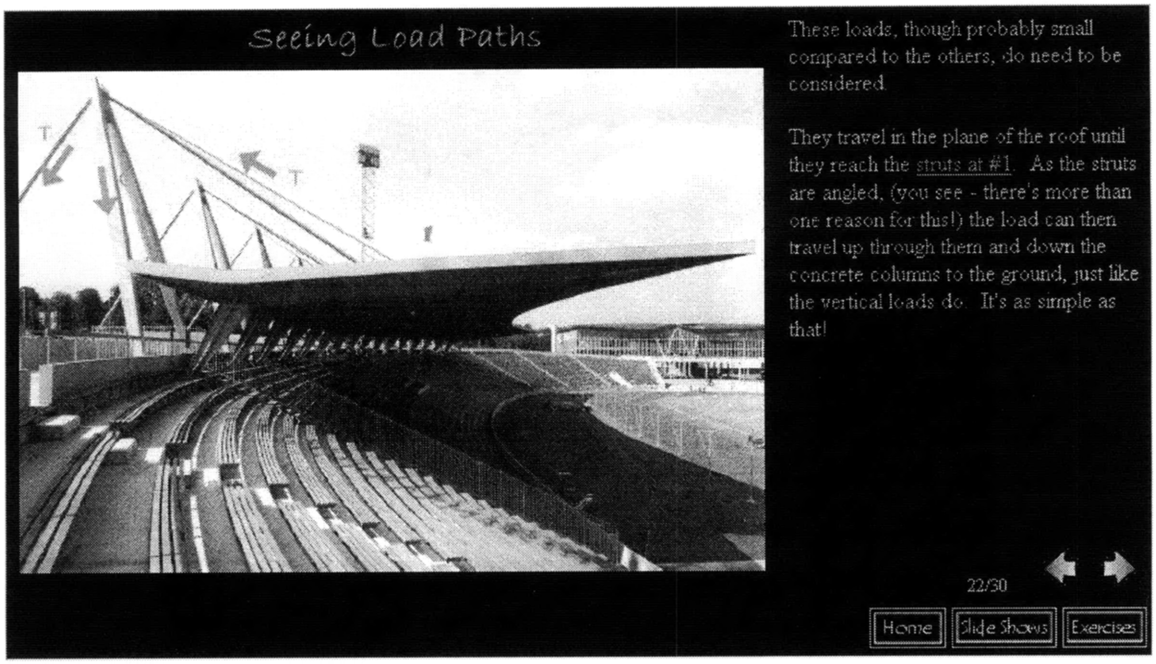

Figure B.28 Screen 22 continues with the stability discussion

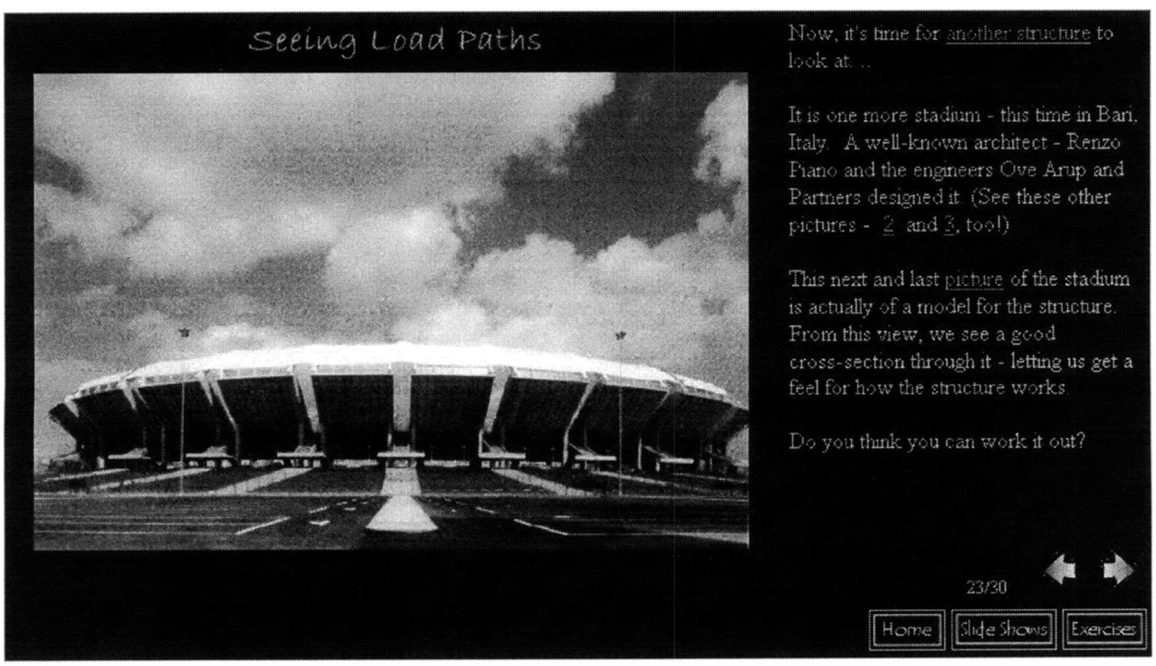

Figure B.29 Screen 23 and yet another structure is introduced (image Ref [19])

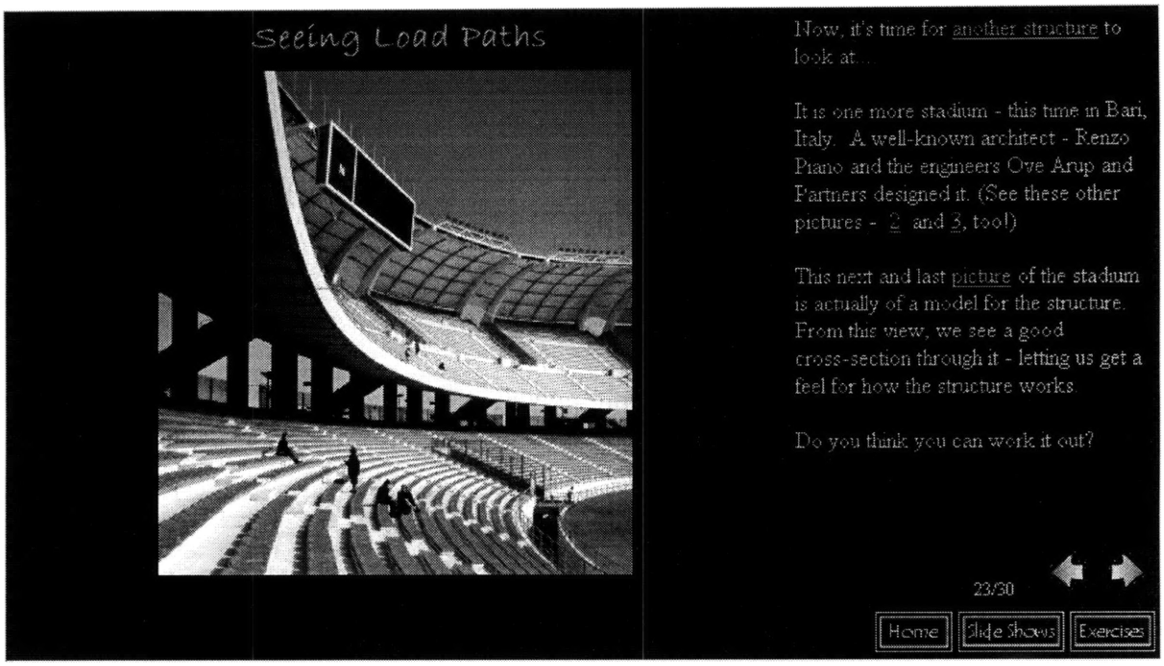

Figure B.30 Screen 23 with a different view of the new structure (image Ref [19])

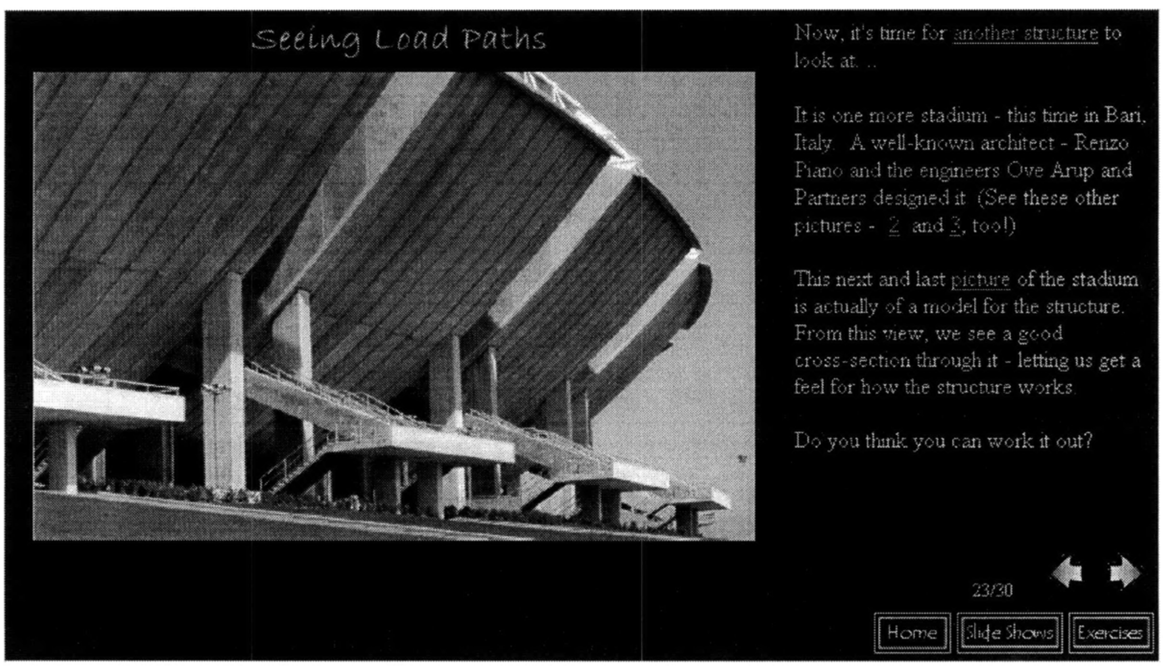

Figure B.31 Screen 23 with another view (image Ref [19])

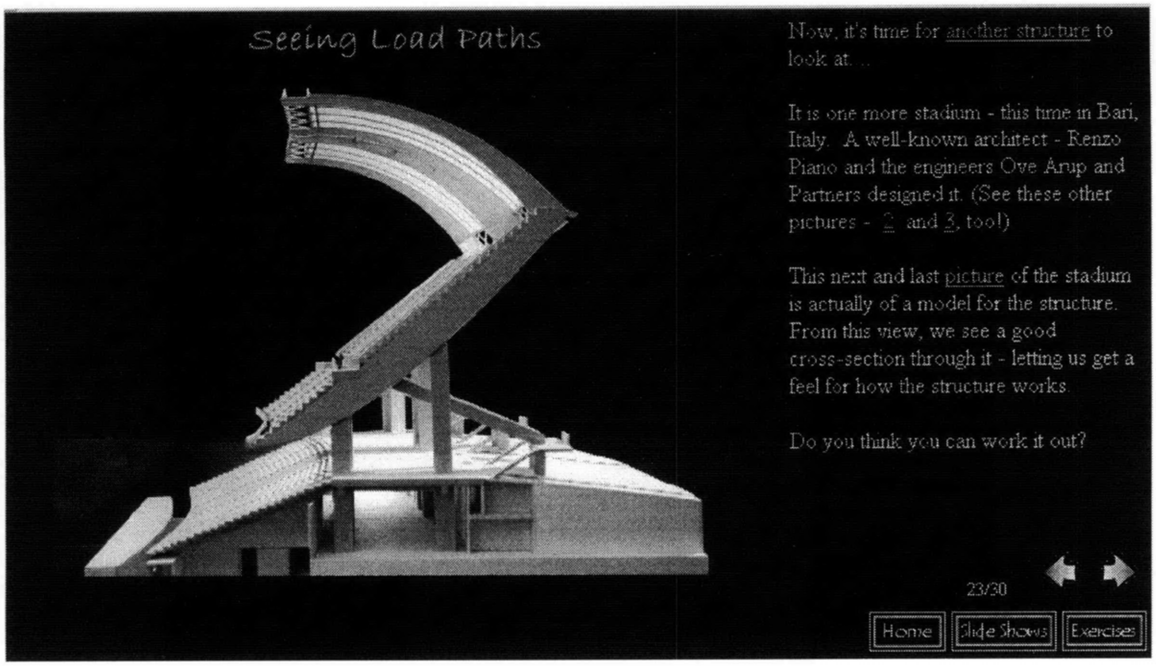

Figure B.32 Screen 23 with the final view to be used in the discussion (image Ref [19])

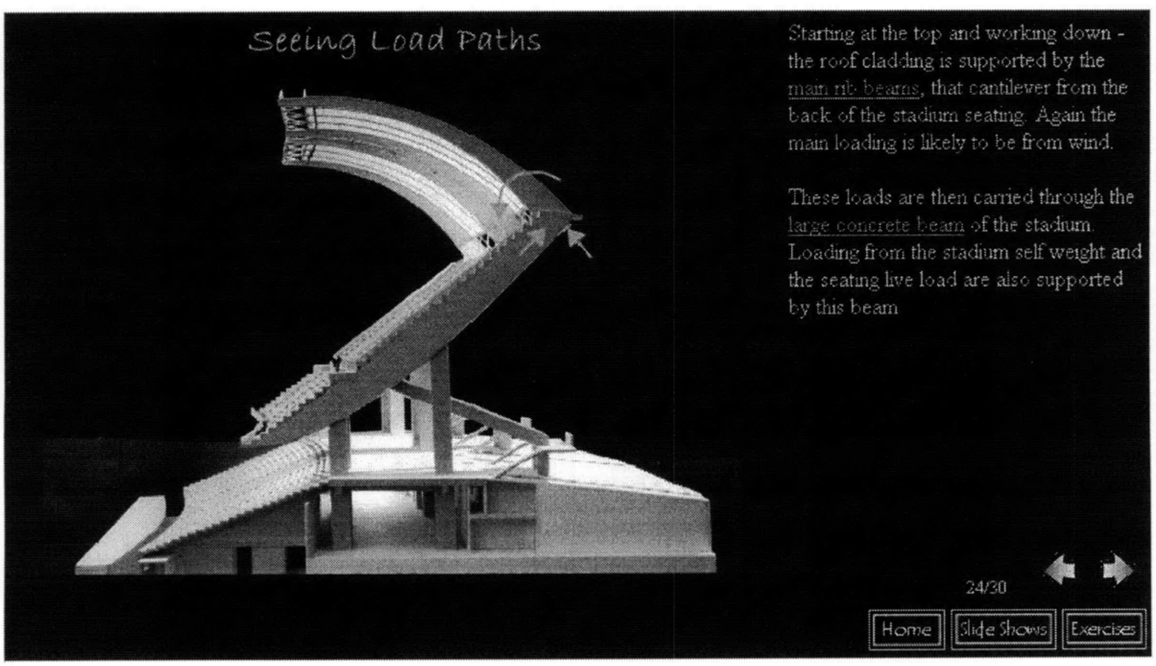

Figure B.33 Screen 24 begins the discussing the load path. The image indicates the reactions caused by the roof rib beams

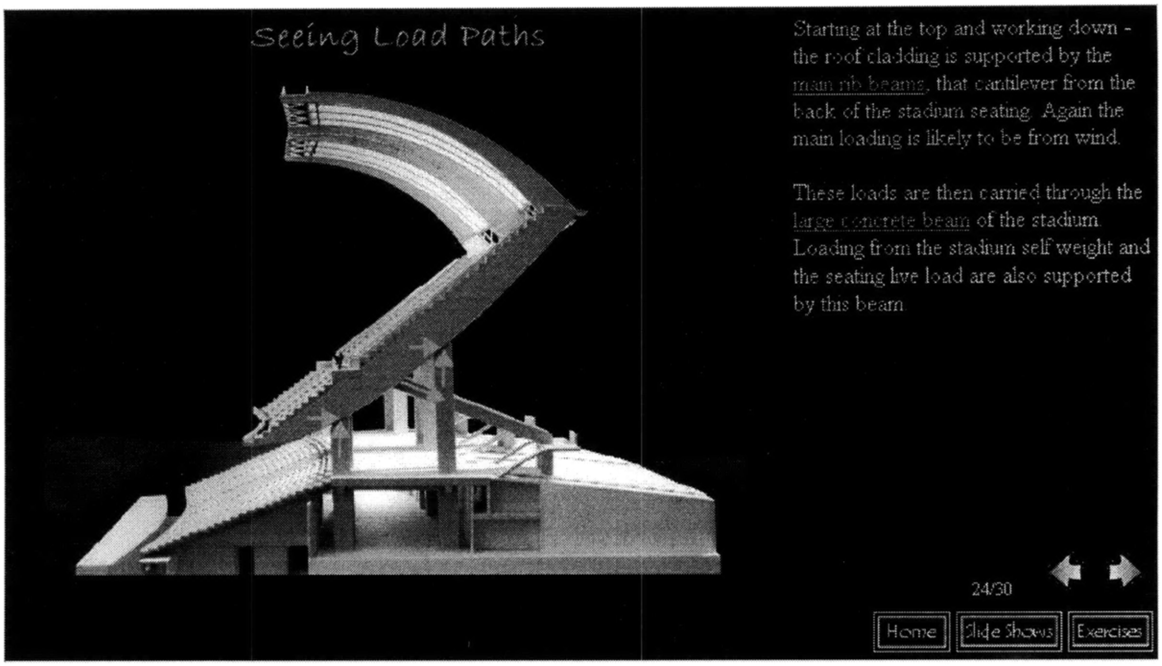

Figure B.34 Screen 24 with the reactions of the main stadium concrete beams marked

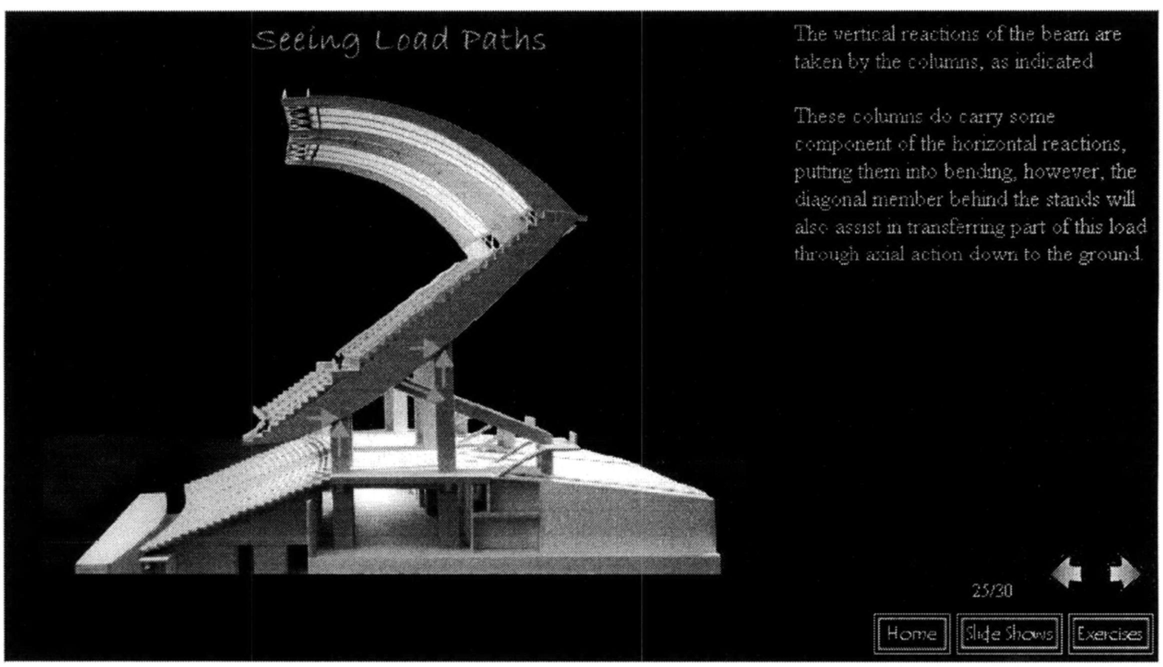

Figure B.35 Screen 25 discussing the transfer of forces from the stadium beams downwards

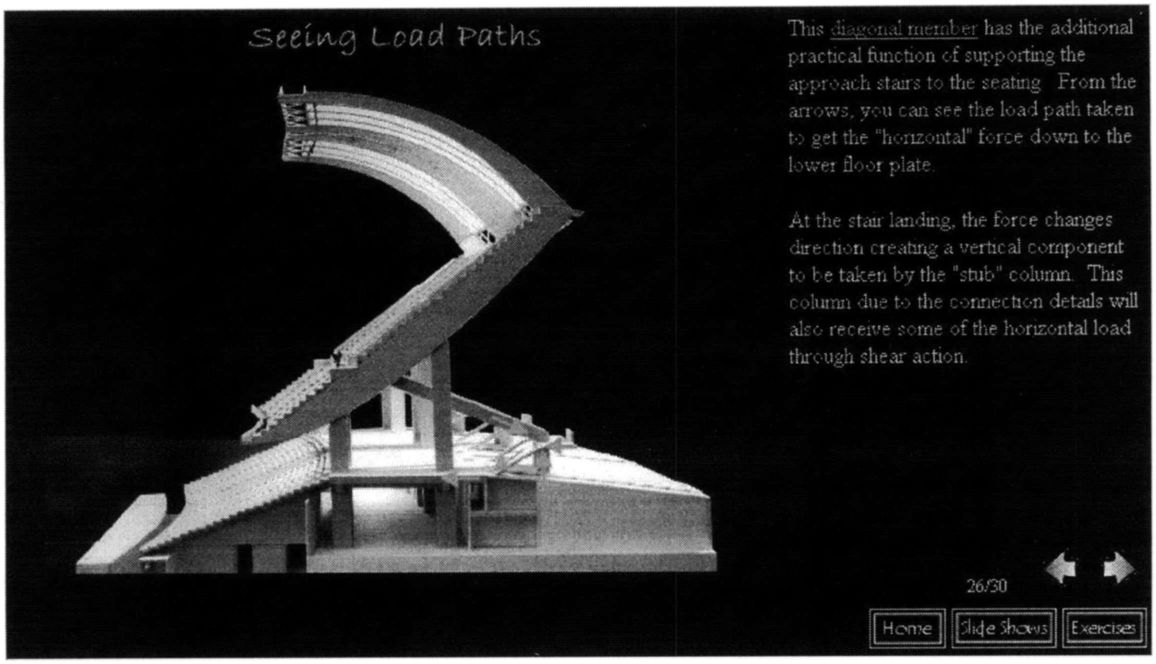

Figure B.36 Screen 26 the final screen spent on this structure reviews the path of lateral loads

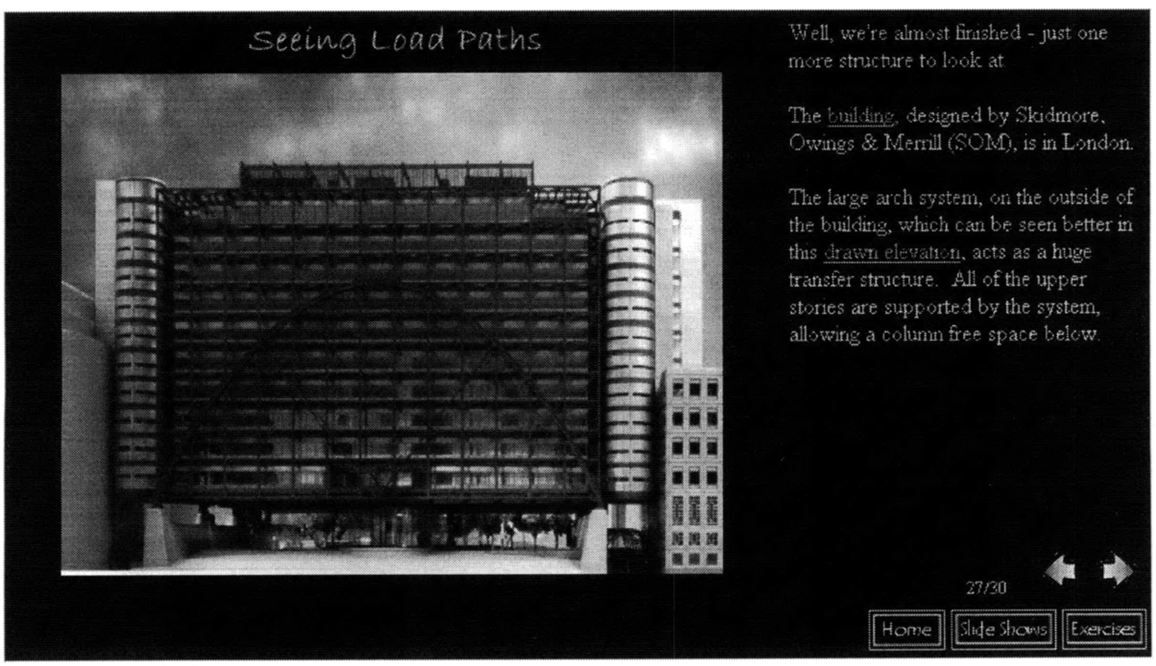

Figure B.37 Screen 27 begins with the final structure to be considered (image Ref [12])

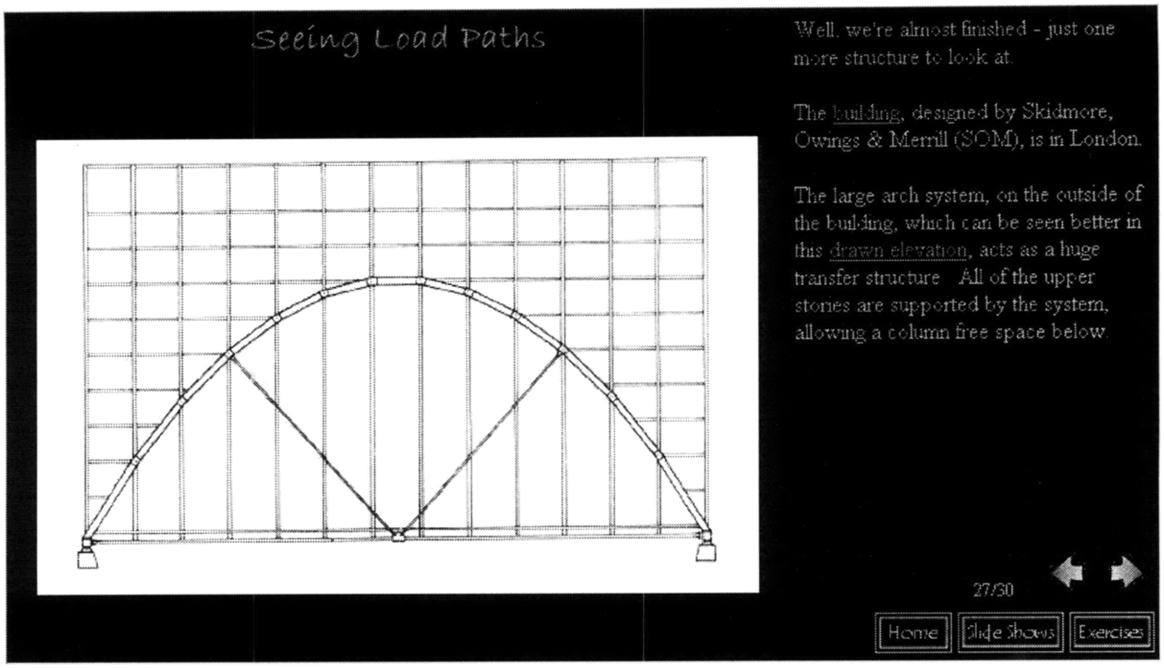

Figure B.38 Screen 27 with a drawn elevation of the structure (image Ref [5])

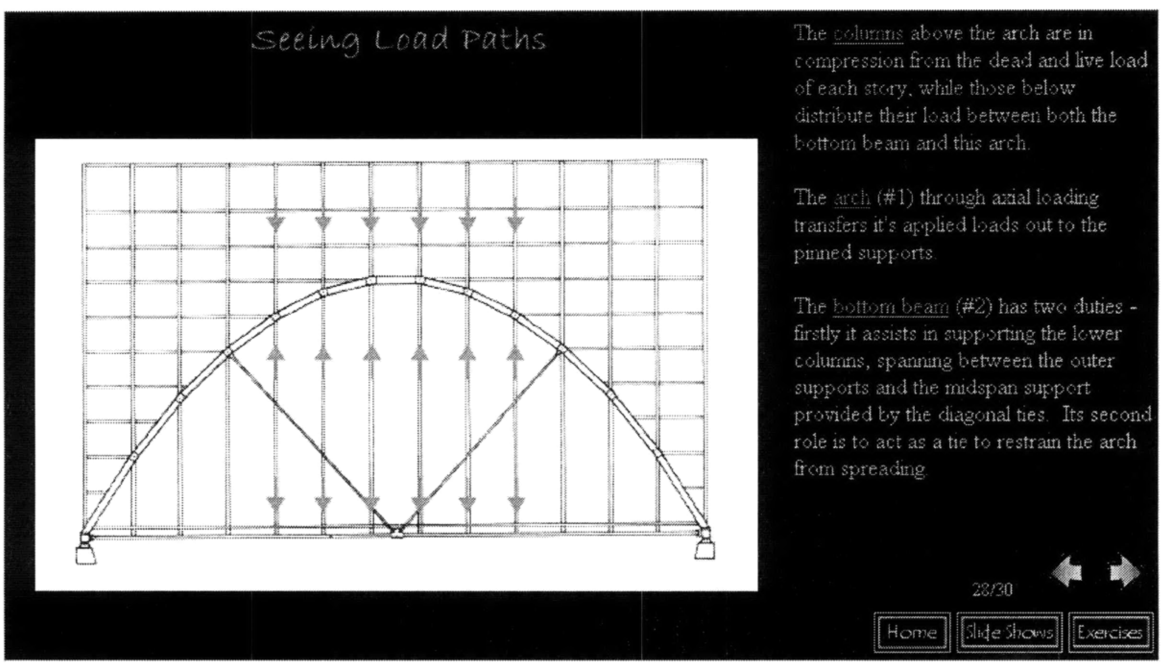

Figure B.39 Screen 28 with image displaying the transfer of load through the columns

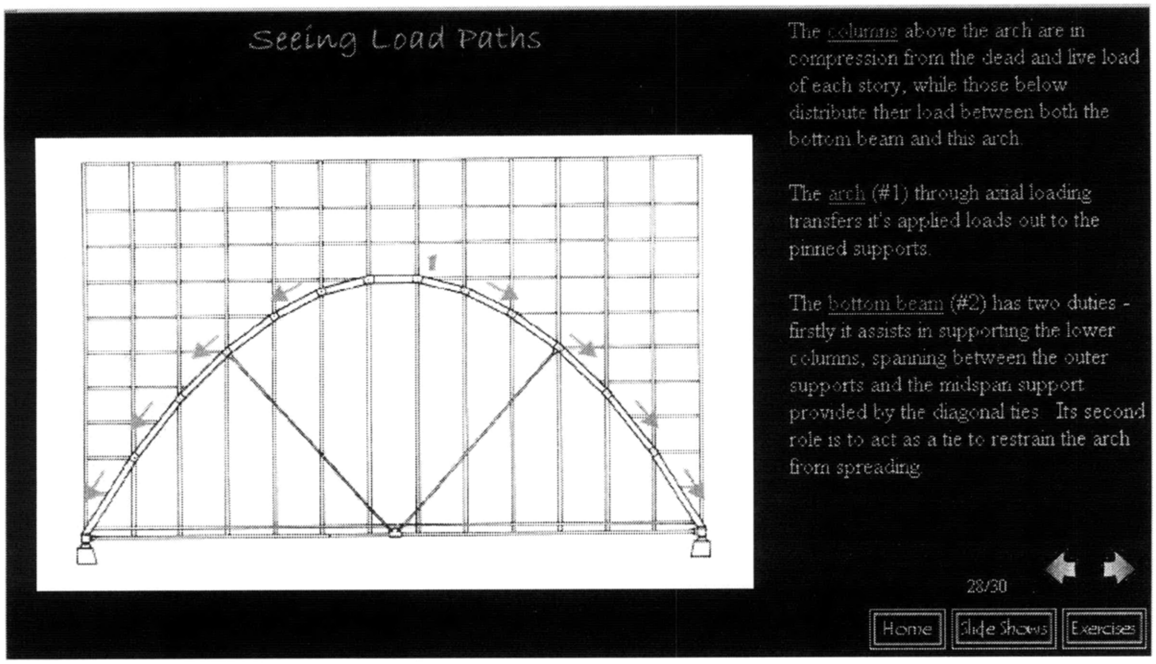

Figure B.40 Screen 28 continuing with the presentation of the load path. This second image shows the arch action of the major transfer element

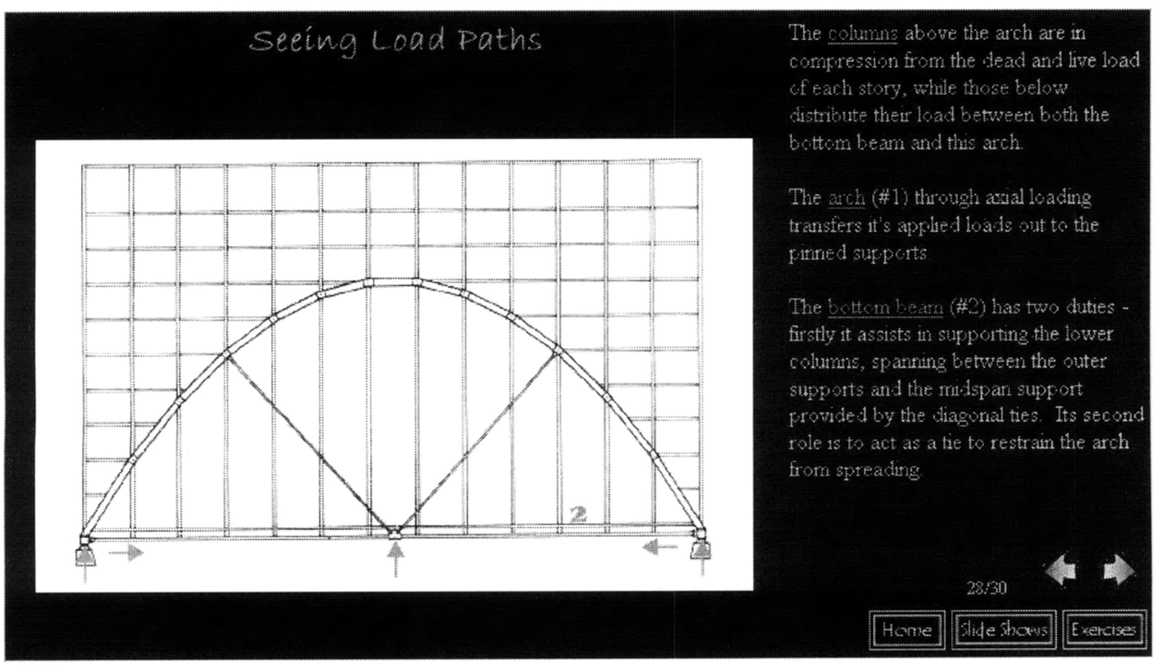

Figure B.41 Screen 28 with the final image considering the reactions of the bottom beam.

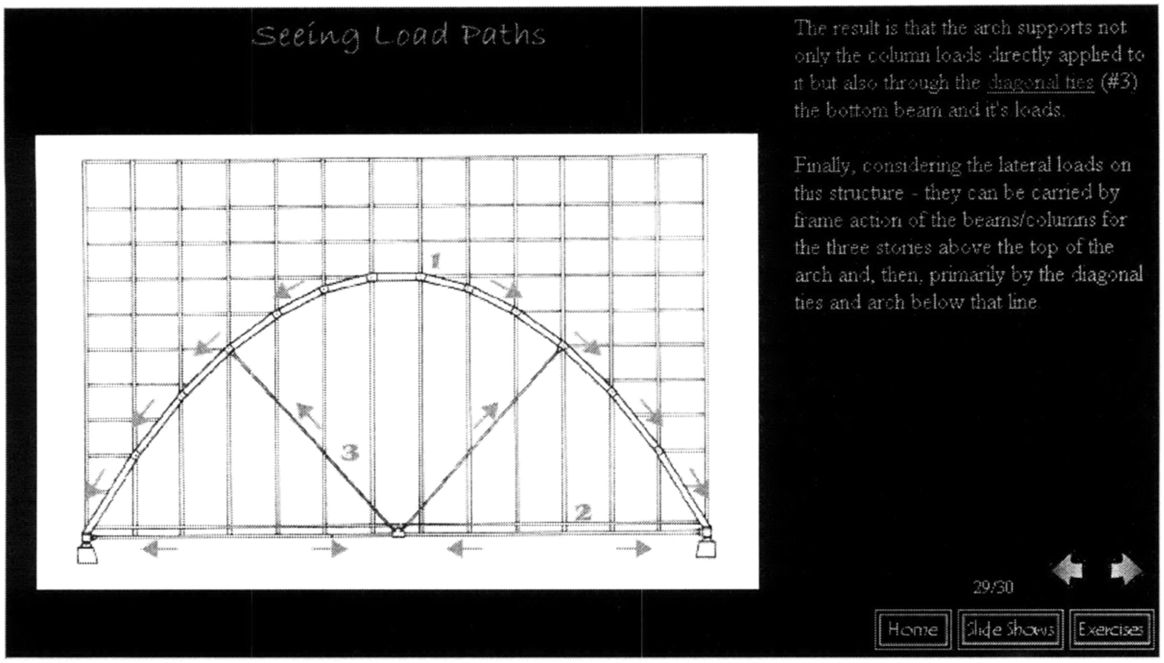

Figure B.42 **Screen 29 finishes up the discussion on this final structure with a comment on the role of the diagonal ties and how the complete system works together**

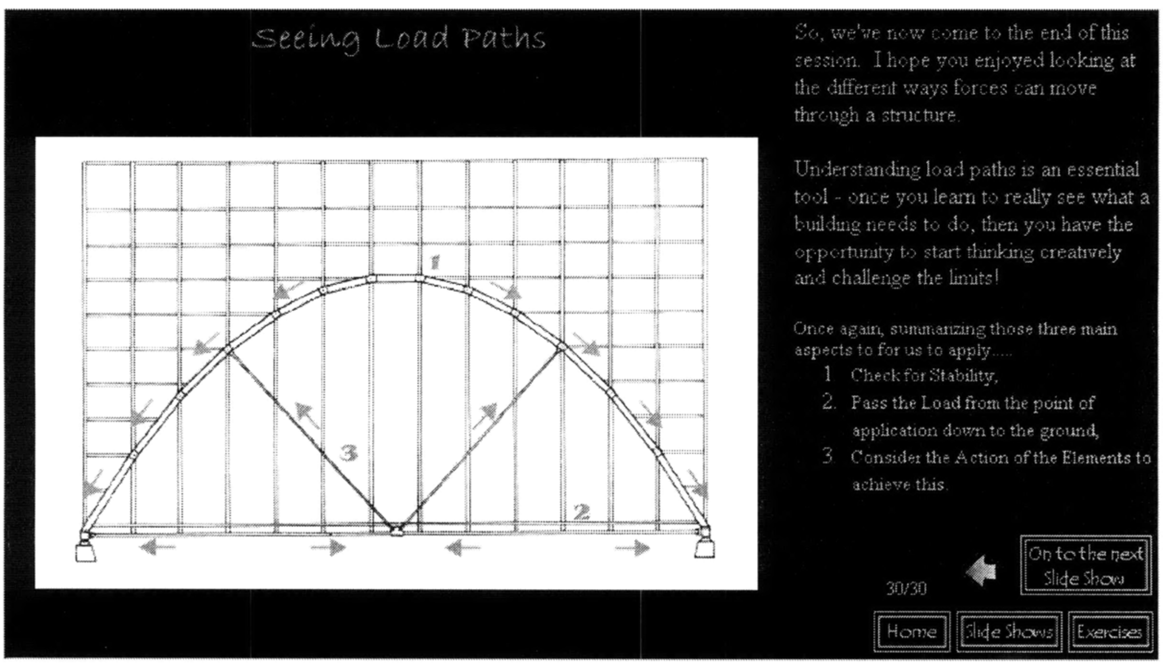

Figure B.43 **Screen 30 the final screen concludes with a last review of the rules to be applied when examining load paths, as summarized earlier**

B.2 Interactive Exercise – "Point Loads on a Simply Supported Beam"

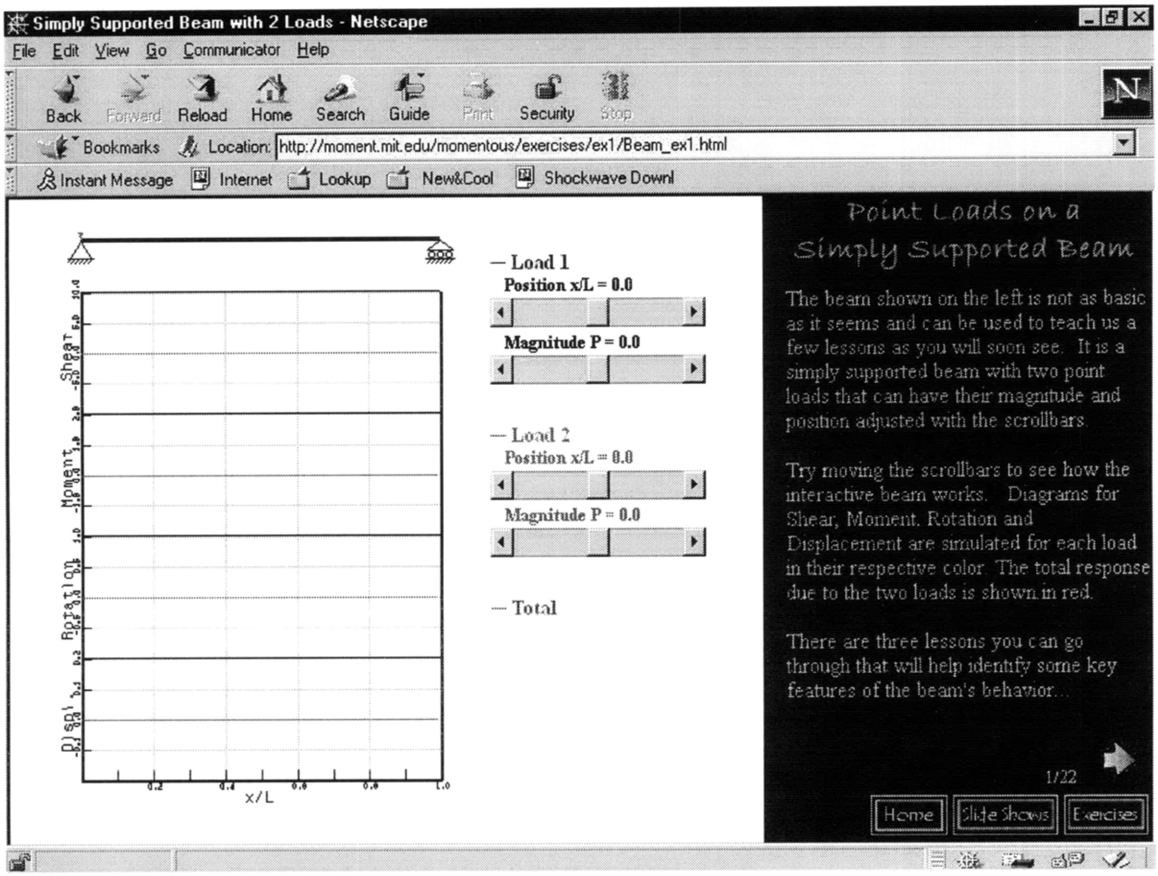

Figure B.44 Screen 1

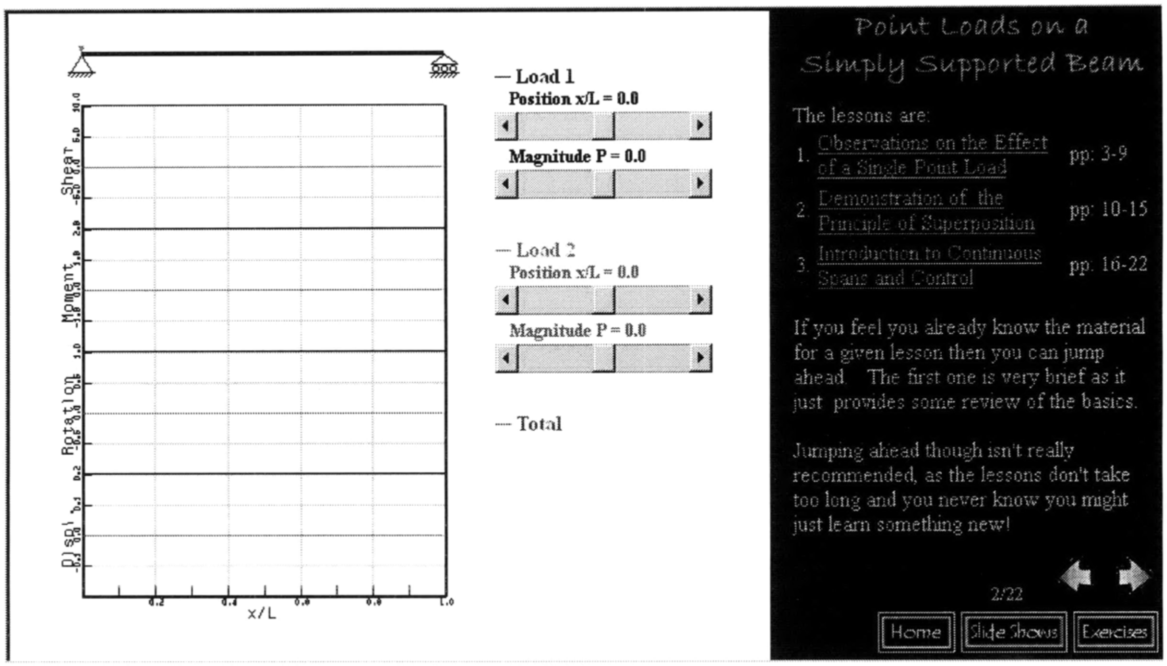

Figure B.45 Screen 2

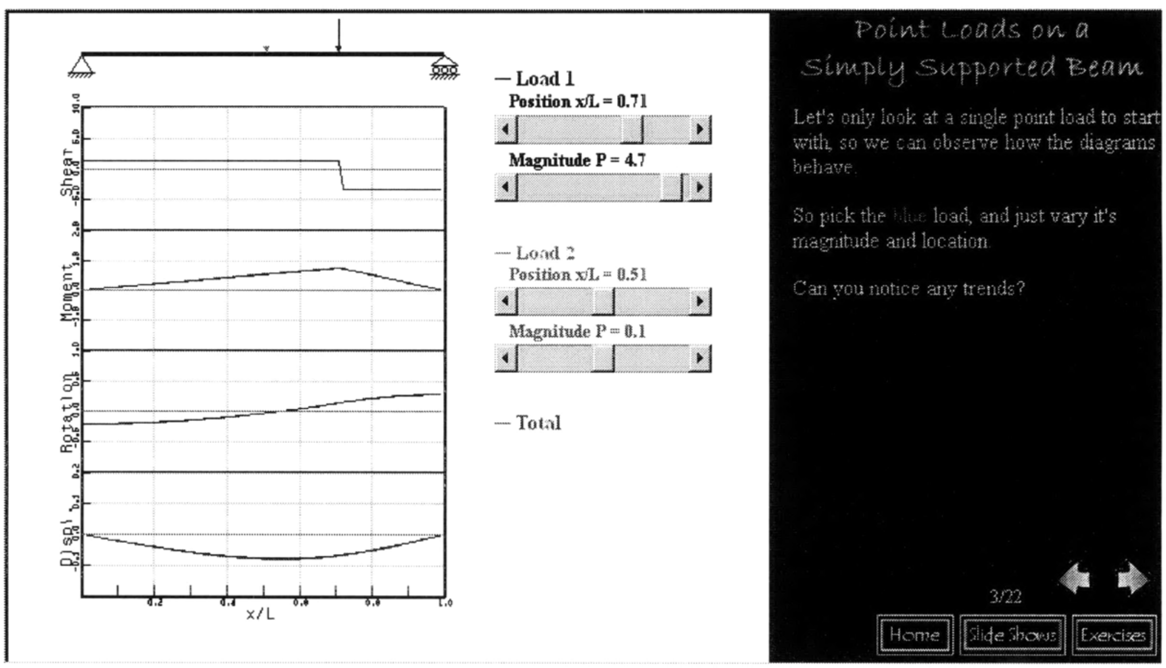

Figure B.46 Screen 3

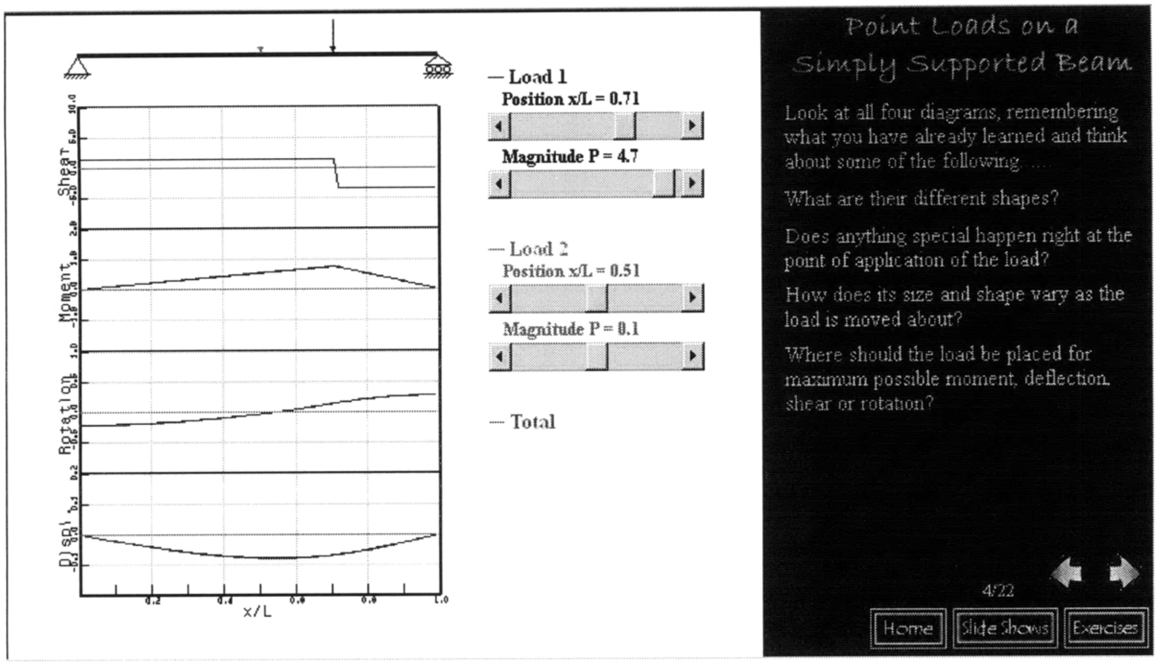

Figure B.47 Screen 4

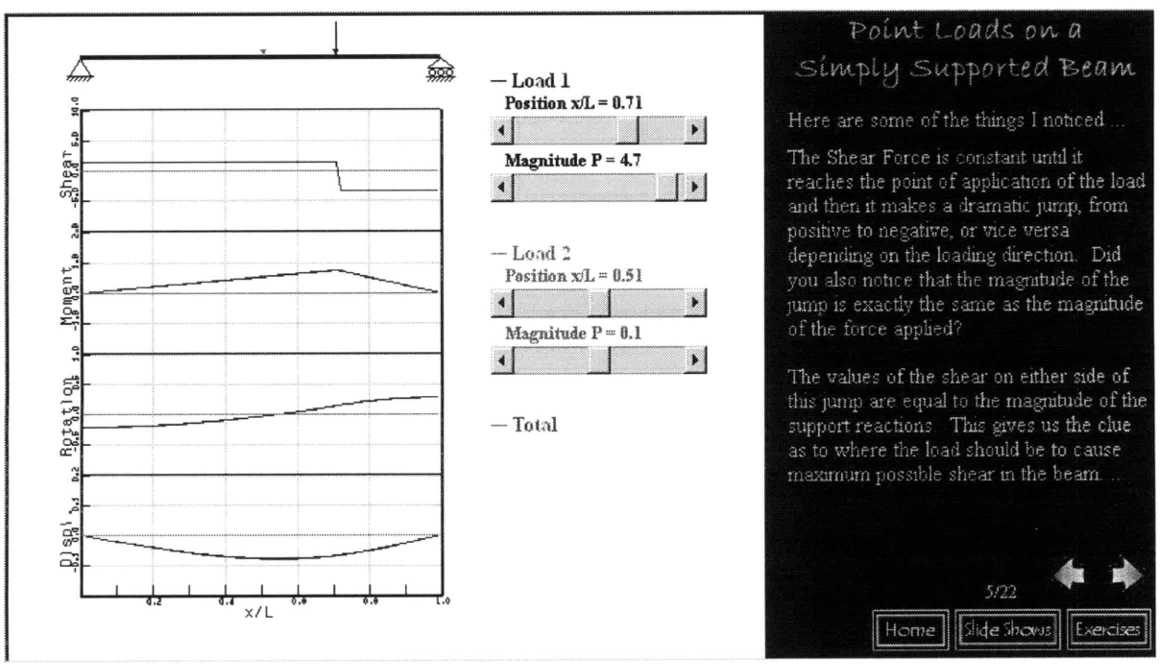

Figure B.48 Screen 5

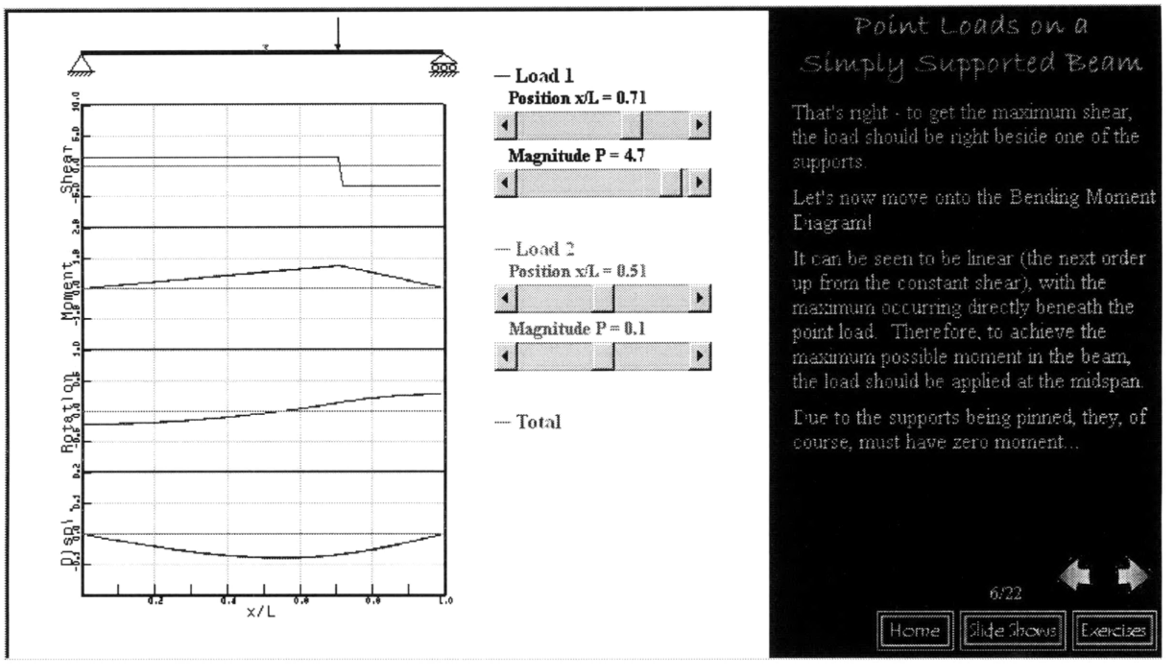

Figure B.49 Screen 6

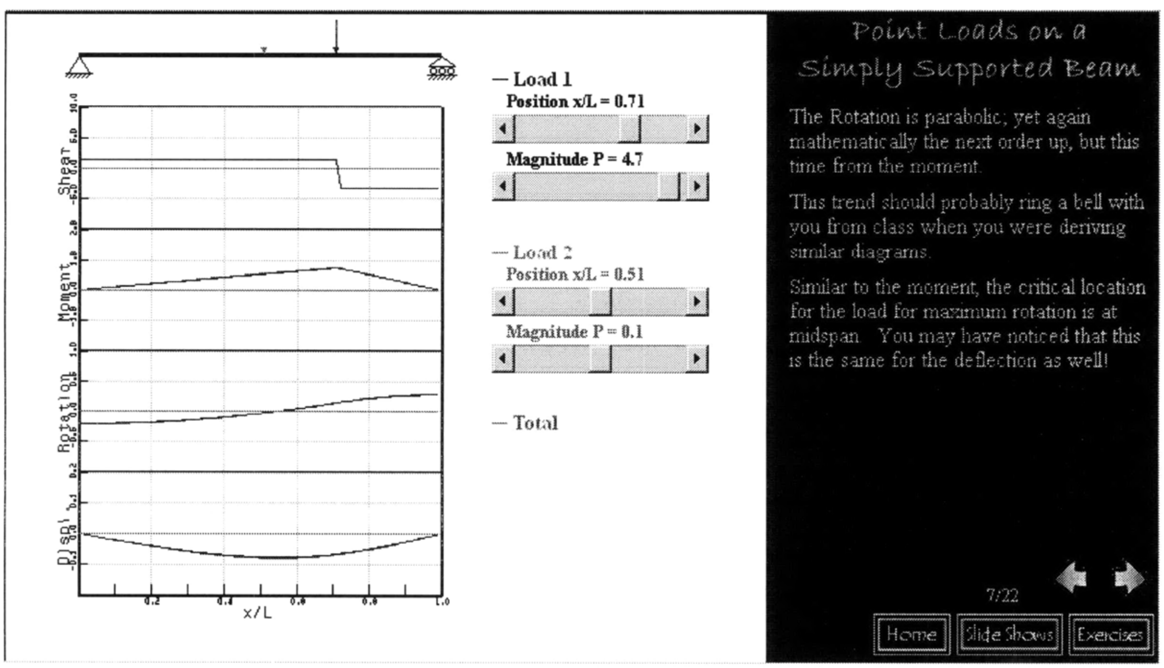

Figure B.50 Screen 7

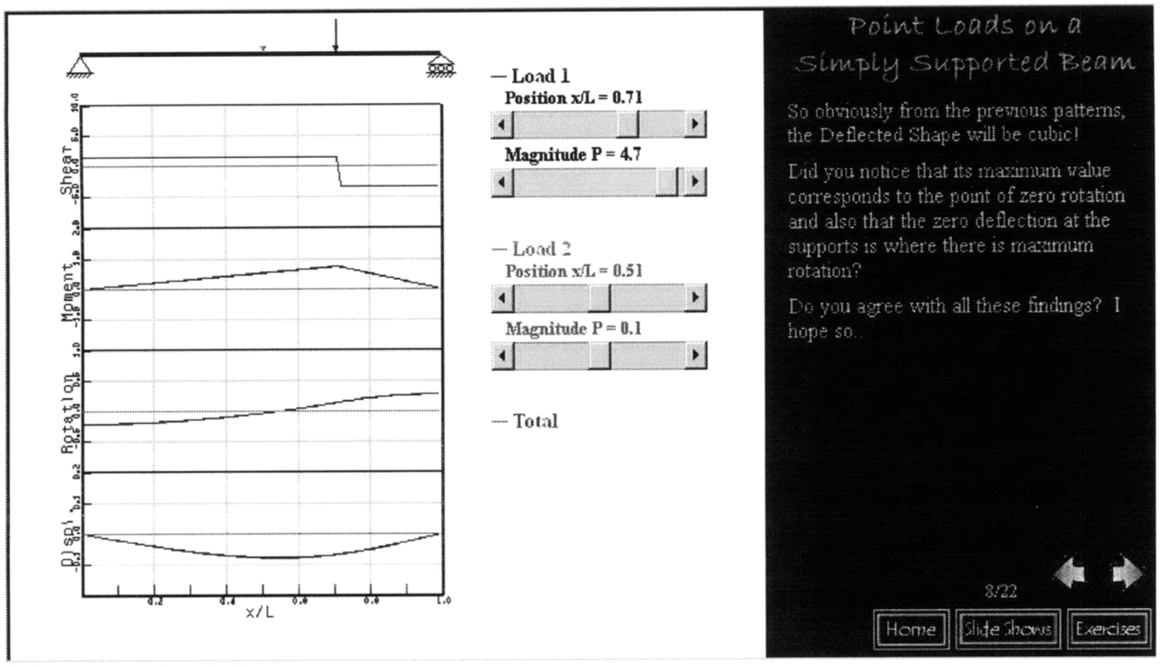

Figure B.51 Screen 8

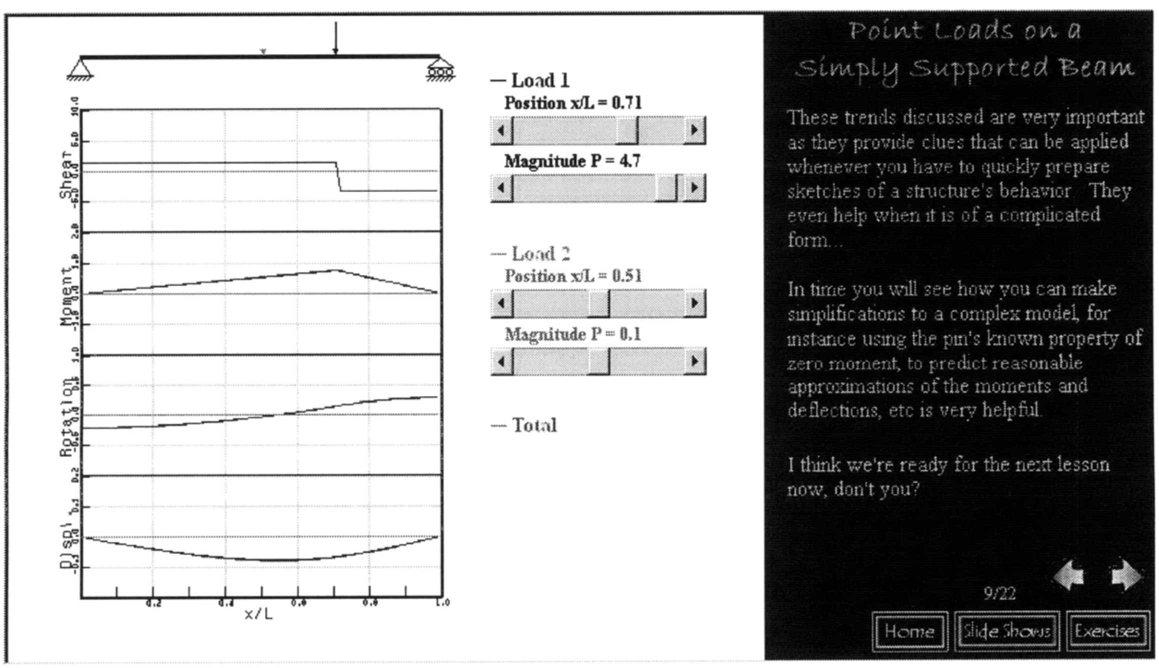

Figure B.52 Screen 9

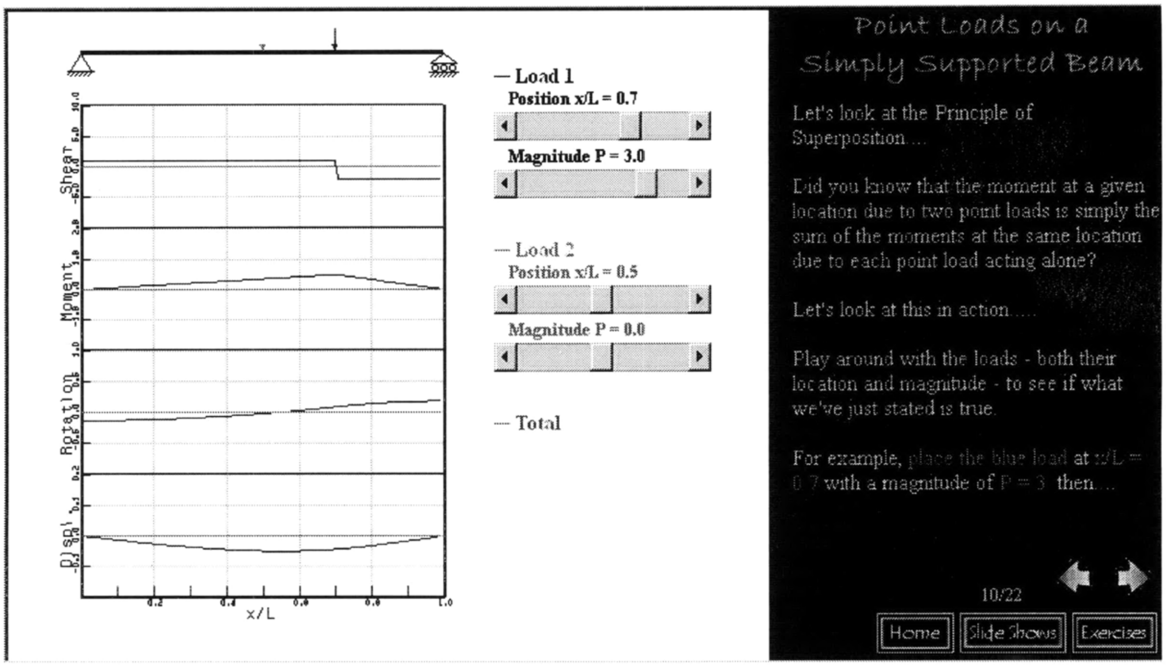

Figure B.53 Screen 10

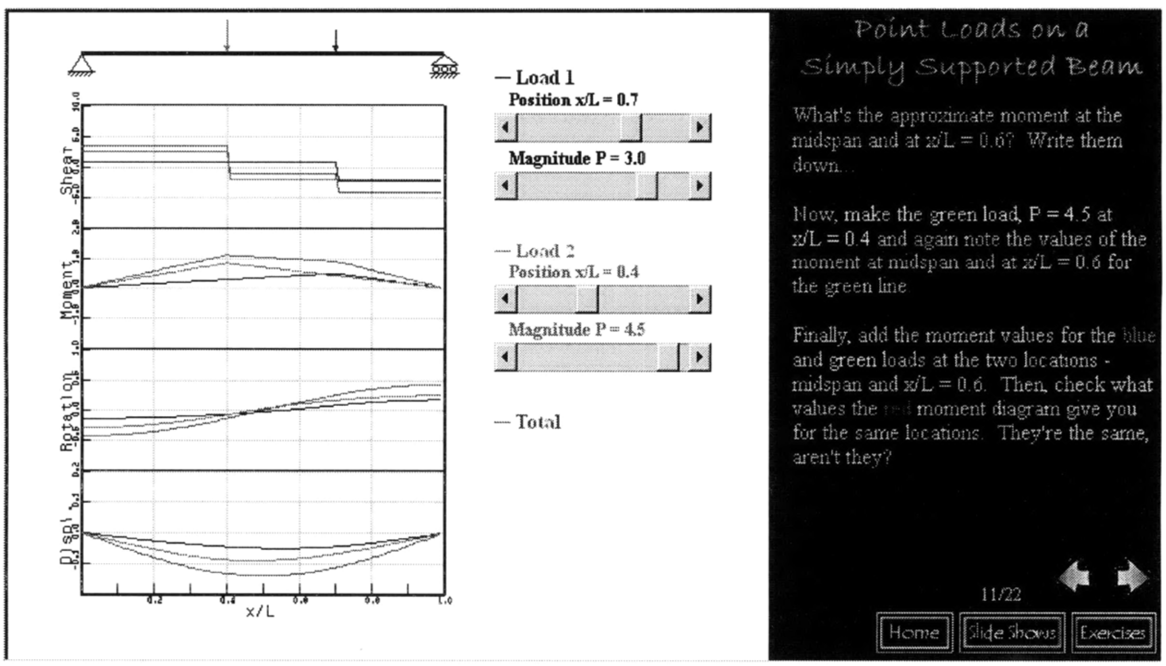

Figure B.54 Screen 11

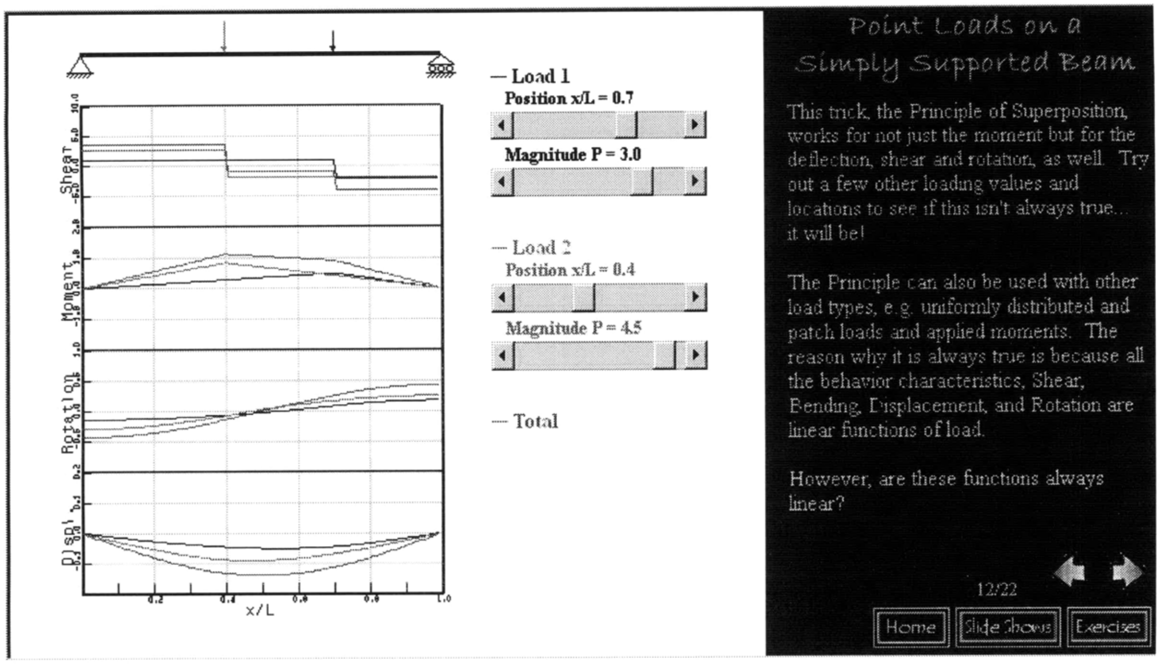

Figure B.55 Screen 12

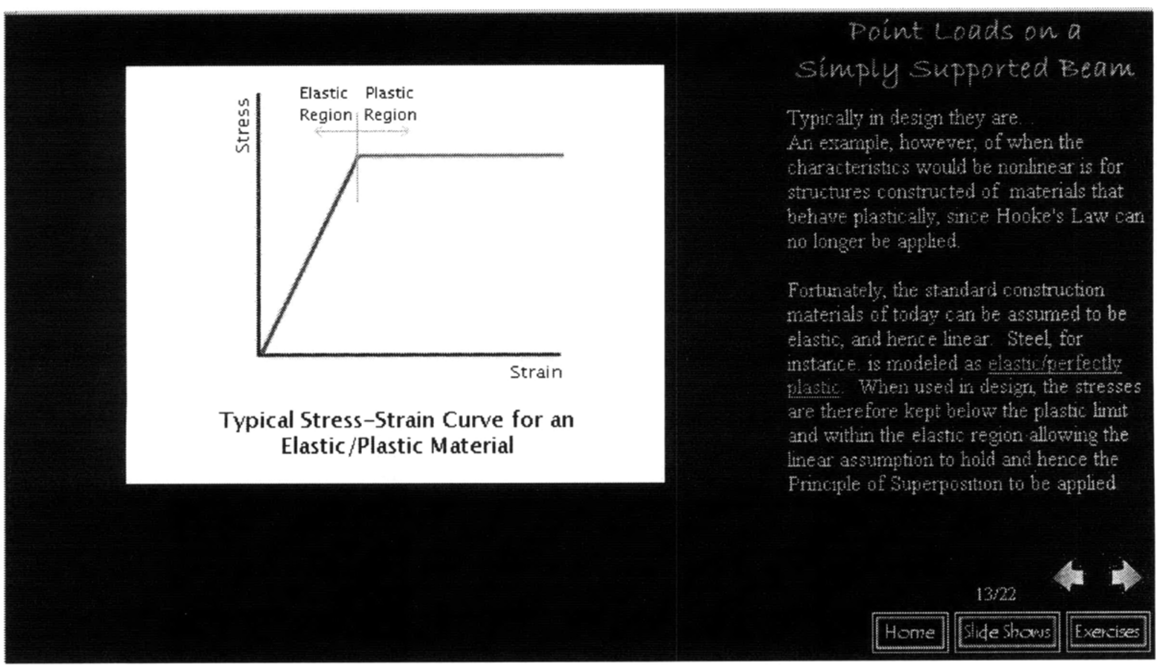

Figure B.56 Screen 13

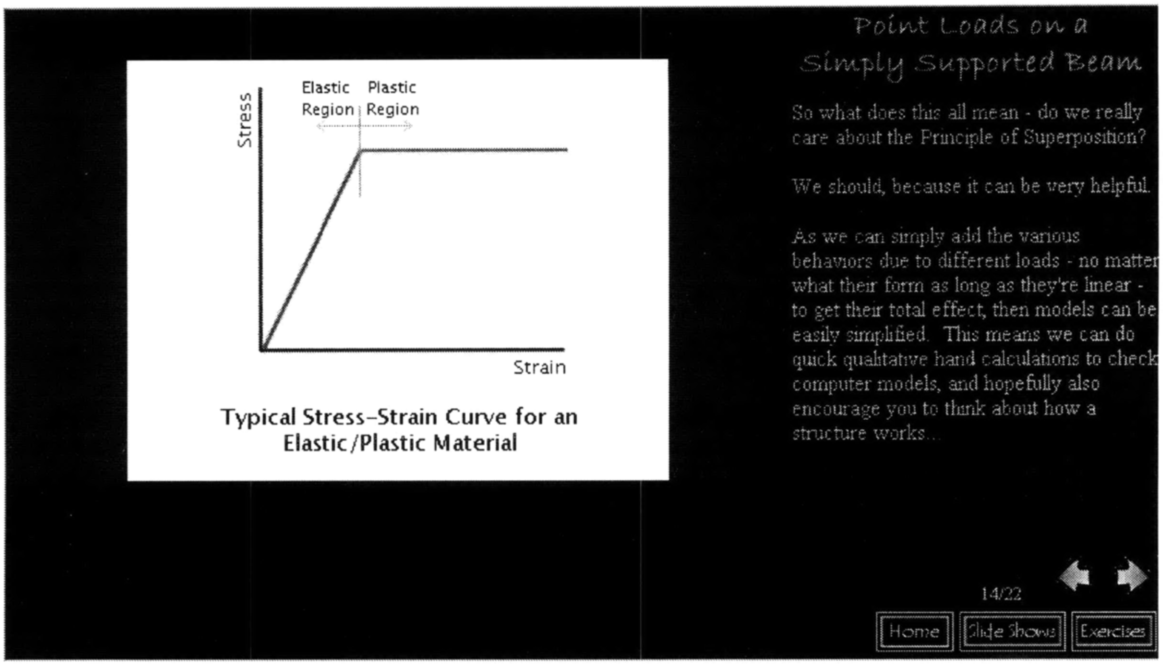

Figure B.57 Screen 14

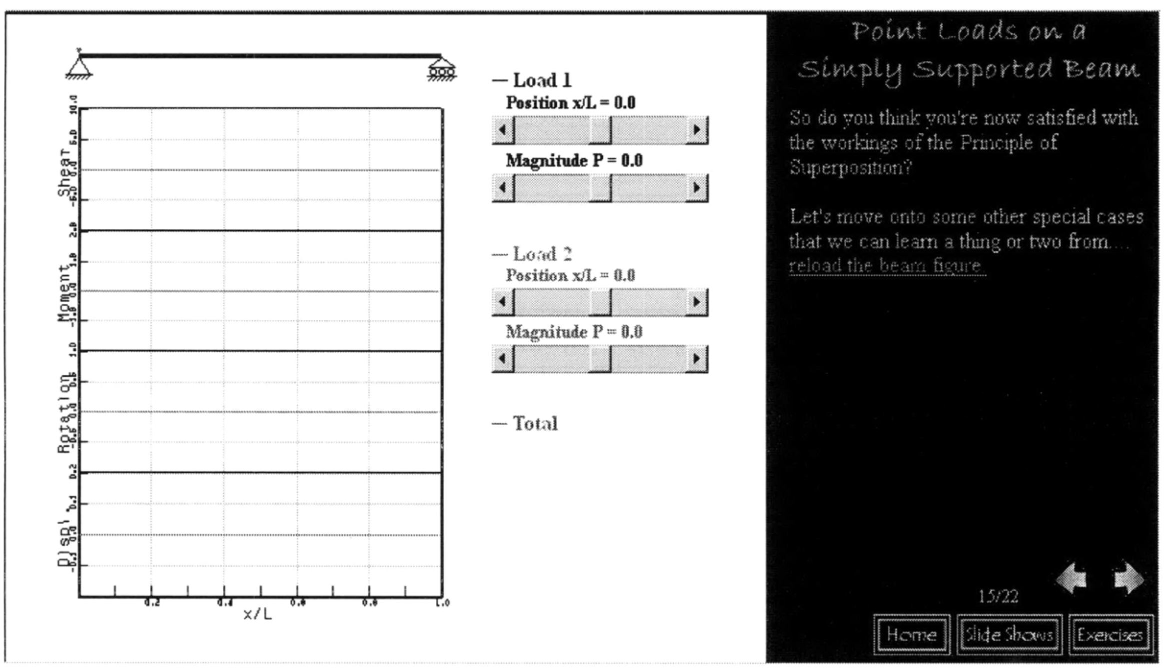

Figure B.58 Screen 15

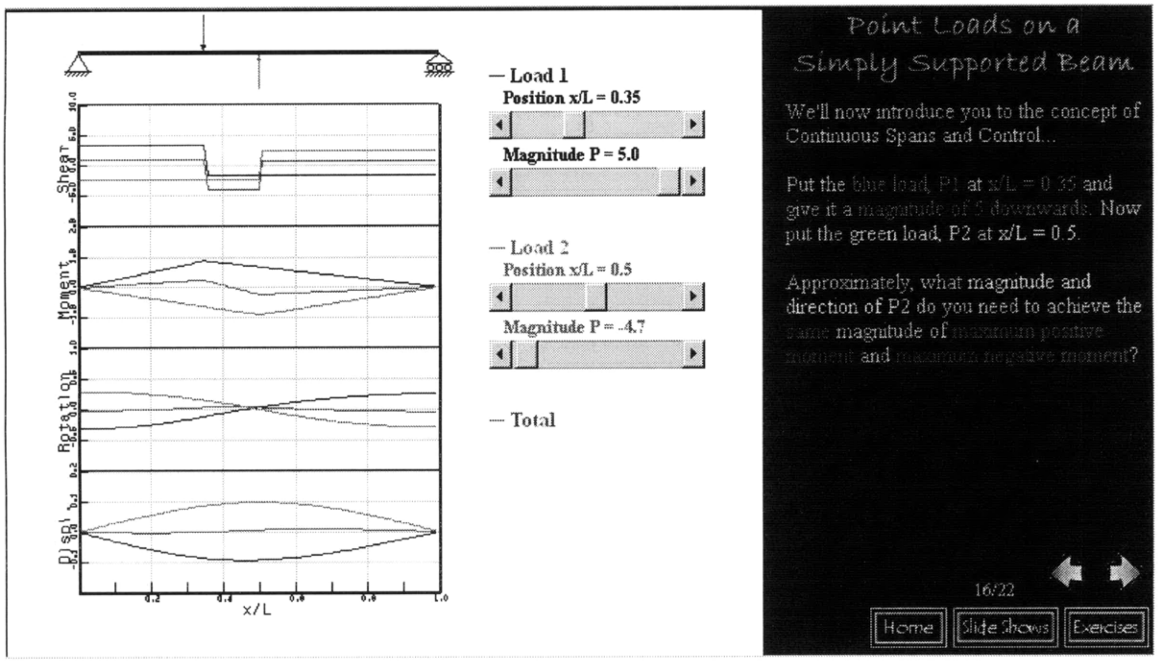

Figure B.59 Screen 16

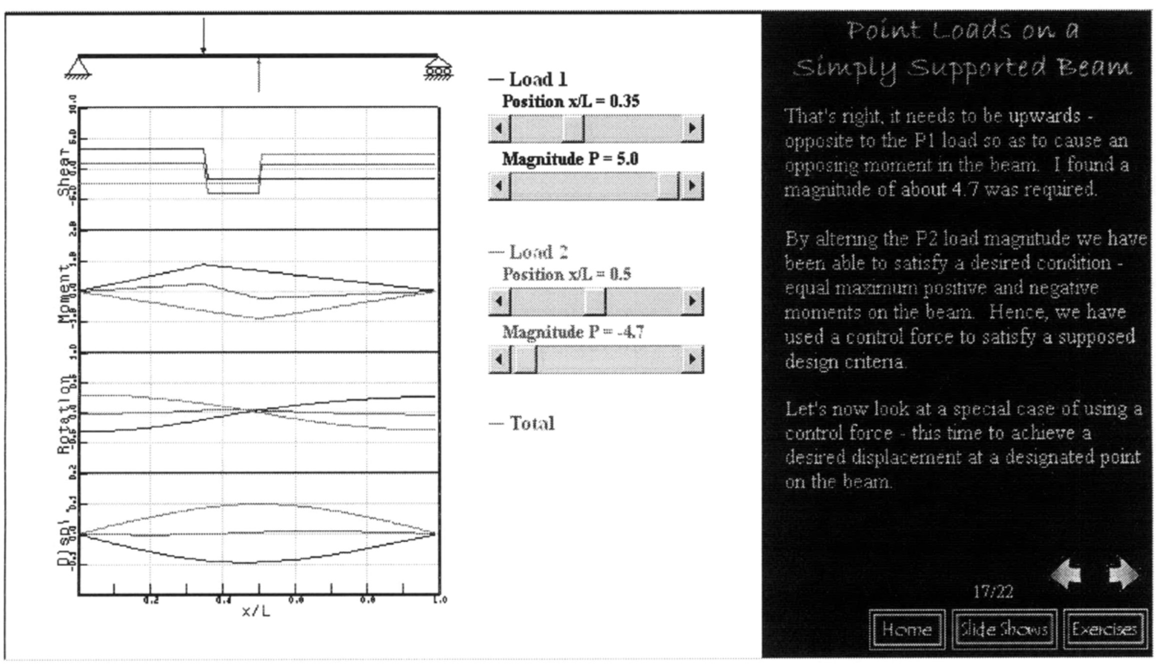

Figure B.60 Screen 17

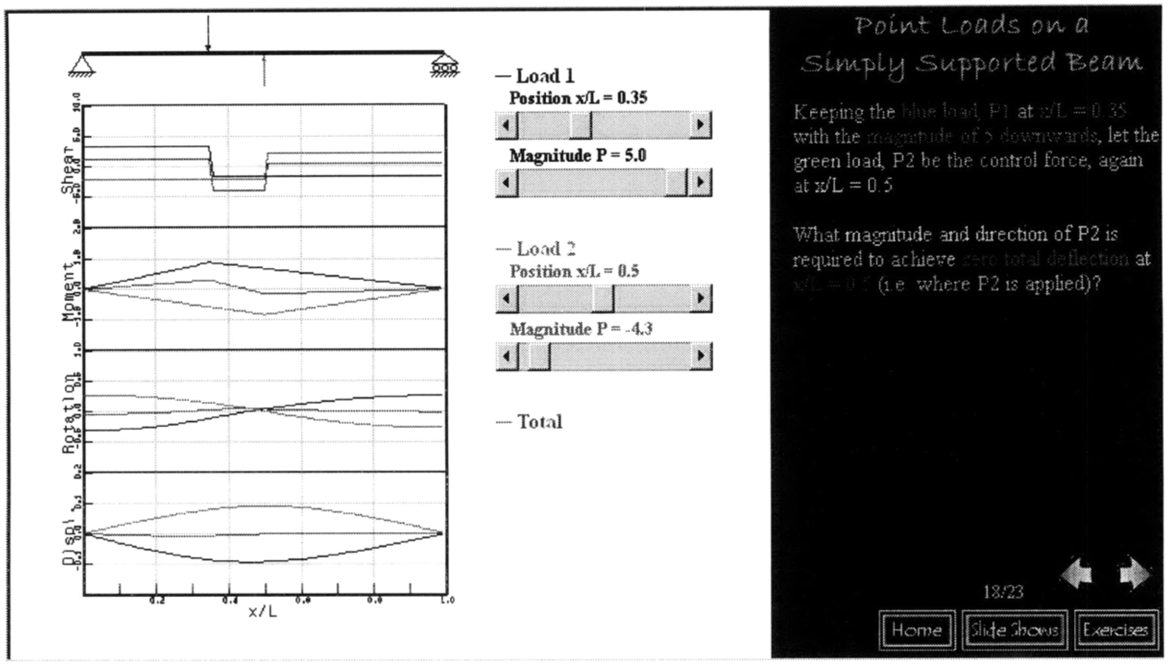

Figure B.61 Screen 18

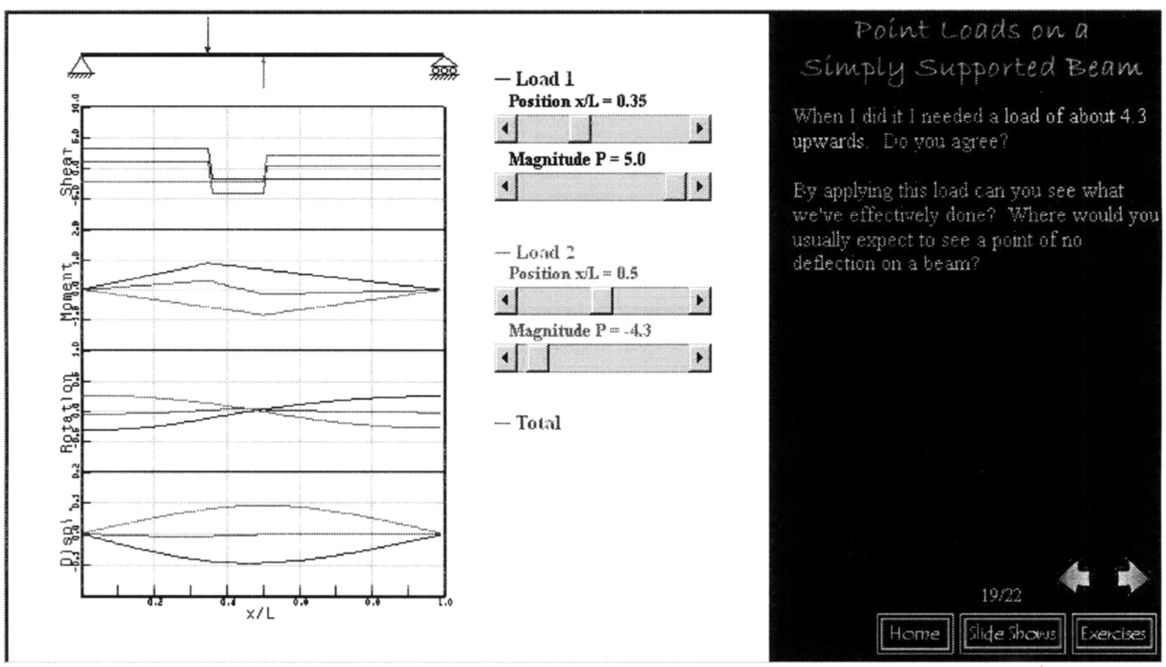

Figure B.62 Screen 19

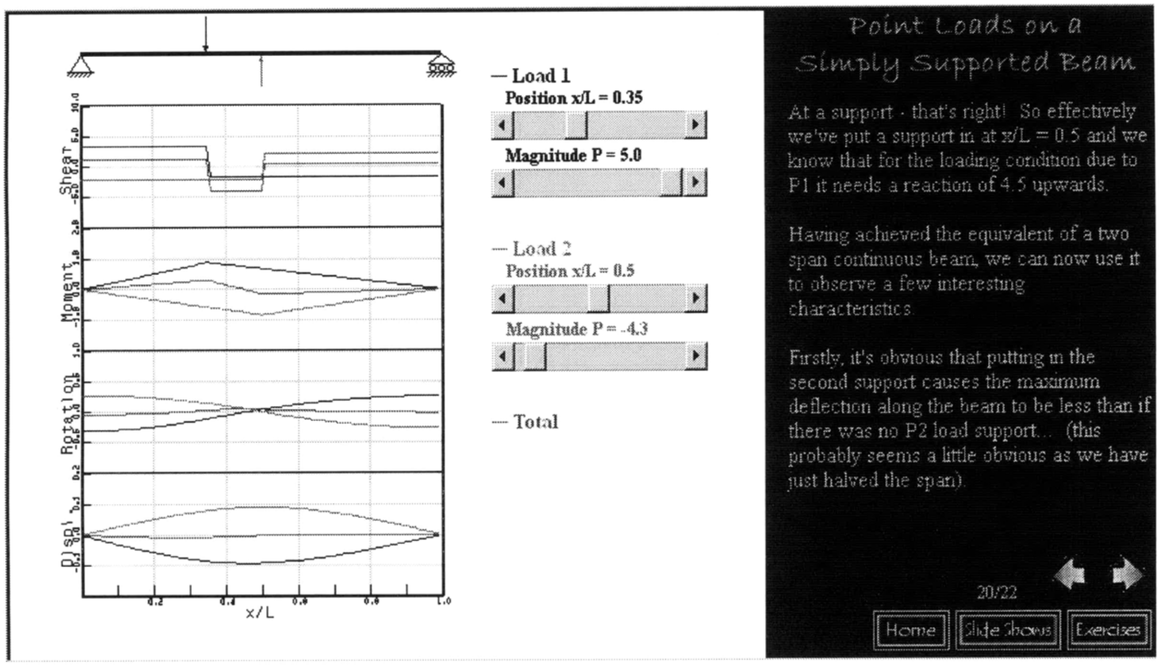

Figure B.63 Screen 20

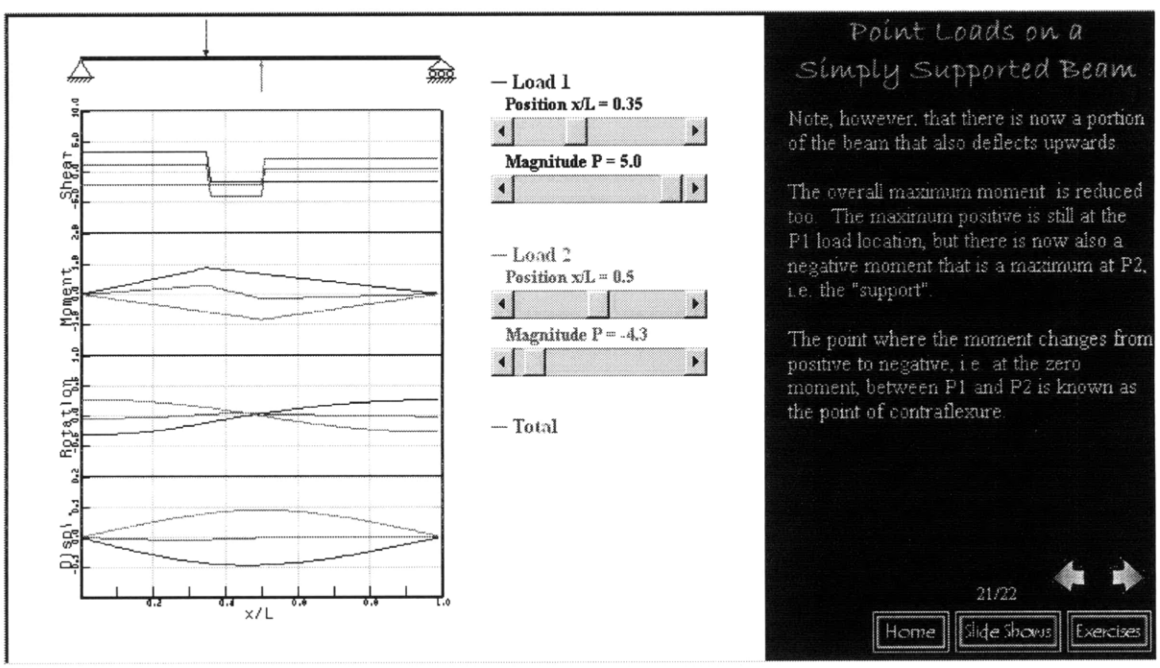

Figure B.64 Screen 21

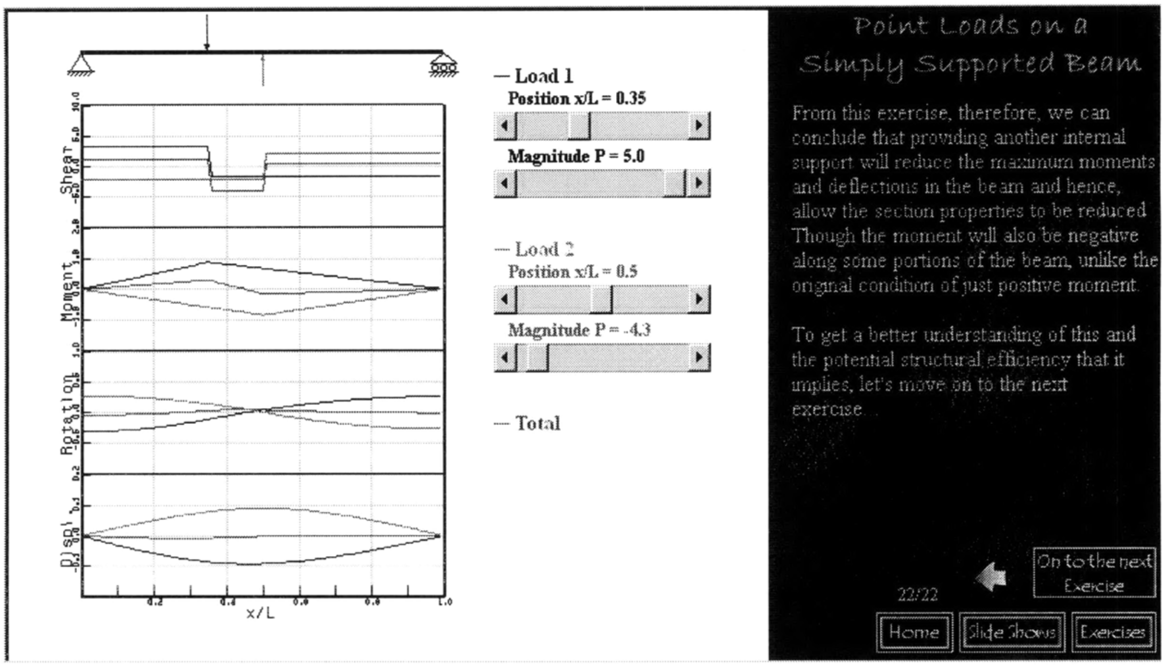

Figure B.65 Screen 22