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by

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A Knowledge Acquisition Study of

Structural Engineers

Performing Preliminary Design

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Abstract

This paper describes interviews with experts in structural engineering. Video recordings of the experts performing preliminary structural design for three buildings were obtained. The knowledge acquisition process is described and the conclusions reached are presented. The conclusions are discussed in terms of level of design detail, solution time, distribution of process and domain activities, the use of previous information in the design process, and the use of sketches.

1 Purpose

As part of current research in the Department of Civil Engineering at Carnegie Mellon University, a knowledge acquisition study of structural engineers was performed. The experts interviewed in this study performed preliminary design of three buildings. An understanding of the design methods that experts use can help in the development of new computer-based tools for design.

The primary purposes for the knowledge acquisition study were:

- to determine the process by which structural engineers design, i.e., whether top-down, bottom-up, or using some combination of these two approaches;
- to determine what spatial characteristics are important in developing structural systems;
- to determine what functional concerns control the selection and placement of structural systems; and
- to determine whether structural engineers think in terms of two-dimensional or three-dimensional systems, and if in terms of two-dimensional systems, then where do the effects of the third dimension enter the design process.

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The first purpose is of importance because the design process of buildings is being modeled by current research in the Department of Civil Engineering at Carnegie Mellon University [Fenves 87] and a computer implementation of the process will ultimately be interfaced to human engineers. If the computer implementation is similar to engineer's methods, then it will be easier to provide an user interface to the system. If the engineer can not understand how the system is approaching the design then the engineer is unlikely to make effective use of the system [Ullman 86].

The other purposes listed are significant because they deal with how an engineer develops structural systems and how the design is influenced by architectural considerations. Engineers and architects have communicated their design ideas for many years. Traditionally the medium has consisted of blueprints, sketches, and specifications that are passed between parties. Yet an architect and an engineer can cooperatively design a facility without these items (as described by the second expert); therefore some type of language or communication process must be present It is the intent of the knowledge acquisition to determine the fundamental aspects of this language.

In addition to the above stated purposes for the knowledge acquisition, secondary purposes of the study are:

- to establish what information is minimally required from an architect to develop a structural system;
- to understand how the engineer uses the architect's constraints or recommends modifications to those constraints which change the architectural plan; and
- to provide test cases for which the proposed computer system can be compared with expert solutions.

Finally, the example buildings solved by the experts will provide test cases for the computer implementation under development Tie computer implementation can then be checked to see how it operates as compared to the experts.

2 Approach

Protocol analysis was used for performing the knowledge acquisition. This type of analysis involves presenting an individual with a problem and asking him to "think aloud" while solving the problem [Ericsson 84]. The individual is videotaped while solving the problem so as to capture all sketches, gestures, and mannerisms in addition to the verbal description of the problem solution. Ullman has found that sketches play a significant role in the solution of engineering design problems; therefore the ability to capture the sketches and gestures is a predominant reason for performing a video protocol analysis in this study [Ullman 86].

Protocol analysis differs from other approaches of knowledge acquisition by recording the problem solution as it happens. Approaches such as retrospective reporting involve the subject explaining at a later time what was done while solving the problem. The problem with this latter approach is that people have a tendency to report what they perceived happened and not what actually happened [Ullman 86, Ericsson 80]. Ericsson and Simon have shown that thinking out loud during problem solution slows the individual down, but that the order and content of the problem solving steps remain unchanged [Ericsson 80].

2.1. Design of Problems

Three sample problems were developed for which the experts were asked to produce preliminary structural framing plans. These problems were structured so as to force the expert to think about the issues and purposes stated in the previous section. The problems were made simple to eliminate many outside considerations that might otherwise hide the basic design process. Ideas for designing the problems were taken from both UUman's and Wiecha's studies [Ullman 86, Wiecha 86].

Problem one is a rectangular office building with plan dimensions of 100 feet by 200 feet and 15 stories high (figure shown in Appendix A page 35). The floor to floor height is 10 feet. This problem is purposely very simple so that the experts can become comfortable working in front of the video camera and thinking aloud.

The second problem is much like the first one so that many calculations could be reused. The essential differences is that the building is longer in plan, 300 feet rather than 200 feet, and is 30 stories rather than 15 stories high (figure shown in Appendix A page 36). A comparison can thus be made as to how the additional height of the building effects the lateral systems considered by the experts.

The third problem is not as simple as the previous two. This building consists of two overlapping towers each with plan dimensions of 200 by 200 feet (figure shown in Appendix A page 37). One tower is 15 stories high while the other is 25 stories high. There are two design cases for this building. The first case consists of both towers containing office space. The second case involves placing an atrium in the first five floors of the lower tower. The two overlapping towers present a spatial arrangement different from the previous problems, allowing the study of how building shape may cause different structural systems to be used. The second case allows the study of architectural features and their effect on the structural system selection and placement

The problems are structured in such a manner that spatial conflicts will arise and the solution techniques employed by the experts can be studied. For example, the potential bay sizes for the buildings are such that the experts have to either choose a long span and use heavy sections, or choose a smaller column spacing reducing the need for heavy sections but introducing more columns into the floor plan. The column spacing problem is reinforced by the fact that the floor to floor height is purposely selected small (arguably too small) so that either the experts have to increase the floor to floor dimension or place columns close together. The cores which are provided in each floor plan contain all means of vertical transportation as well as rest rooms. These areas are also chosen small or oriented in the wrong direction in the second and third problems so as to see how the core size and direction influences the expert designer's decisions on structural framing selection and placement

The problem set that was given to all experts can be found in Appendix A. The package given to the experts consisted of the problem set and a sketch pad where all work was to be written. All experts received the same instructions and information about each problem and had a similar place to write their solutions. The sketch pad provided a means for saving their solutions.

22. Method of Protocol Data Collection

The process of administering the problems to each of the experts was kept uniform. The experts were given the instructions shown on the first page of Appendix A. These instructions provided general remarks about **the knowledge** acquisition session and told the experts that a preliminary structural solution should be developed for each problem. The experts were given one problem at a time so that their attention would be focused on only one problem. Following the completion of the problem solutions, a series of questions were asked to obtain explicit answers to some of the issues that the knowledge acquisition process was addressing. These questions can be found in Appendix A. The experts were videotaped throughout the problem solution and question answering.

The collection process started by using a faculty member within the Civil Engineering Department at Carnegie Mellon for calibration of the time required to solve the problems, and to verify that pertinent information for problem solution was present Following this procedure two practicing structural engineers were interviewed.

23. Method of Protocol Data Analysis

The videotapes were transcribed to record the statements and actions of the individual during the solution of each problem. After the transcript was made, a classifier was assigned to each action of the expert These classifiers were verified by a second viewing and in some cases by additional viewing by another individual. The transcripts for each problem of all three experts can be found in Appendix B.

The classification scheme chosen to represent the experts' actions is divided into *the Junctions* of planning, action, and evaluation. The classification is also divided into *subject* areas of *process* and *domain.* The process activities are actions dealing with how to plan or evaluate the design steps, while the domain activities deal with the spatial, structural, architectural, and mechanical aspects of the design. The domain subject is further subdivided into *spatial* (syntactic) and *semantic* (functional) kinds of information. This latter separation is in agreement with the classification chosen for a structural design grammar under development [Fenves 87]. A complete list and description of the classification categories is given below.

- ***Input:*** Actions such as reading the problem statement and receiving answers to questions.
- *Process **Plan:*** Actions that plan the course of problem solving.
- ***Domain Plan** ISt:* Structural planning actions. This is a functional (semantic) activity.
- ***Domain Plan** ISp:* Actions which plan spatial concepts. This is a spatial (syntactic) activity.
- ***Domain Plan** IA:* Architectural planning actions. This is a functional (semantic) activity.
- ***Calculation:* All** actions of calculating values either by using a calculator, referencing previous calculations, or looking up information in a handbook.
- *Sketching:* Actions of drawing on papa*.
- *Process Decision:* Decisions about the problem solving process.
- *Domain Decision /St:* All structural decisions. This is a functional (semantic) activity.
- *Domain Decision ISp:* Actions involving spatial decisions. This is a spatial (syntactic) activity.
- *Domain Decision IA:* Architectural decisions. This is a functional (semantic) activity.
- *Process Evaluation:* Actions of evaluating the course of problem solving taken or planned.

- ***Domain Evaluation*** *ISt:* Actions of evaluating structural aspects. This is a functional (semantic) activity.
- ***Domain Evaluation*** *ISp:* Actions evaluating spatial issues. This is a spatial (syntactic) activity.
- ***Domain Evaluation*** *IA:* Actions which evaluate the architectural aspects. This is a functional (semantic) activity.

Using these above classifiers, all actions of the experts were classified and tabulated to show the amounts and proportions of time that each required for the solution to a design problem.

The activity classifications are aggregated as follows.

The functions are calculated as:

Planning = Process Plan + Domain Plan + Input

Action = Calculation + Sketch

Evaluation = Process Evaluation + Domain Evaluation **+ *Process Decision* +** *Domain Decision*

The subjects are aggregated as:

Process = Input + Process Plan + Process Decision + Process Evaluation

Domain = Domain Plan + Calculation + Sketch + Domain Decision + Domain Evaluation

The subject domain is further decomposed as follows:

Spatial SB *Domain Plan (Spatial) + Domain Decision (Spatial) + Domain Evaluation (Spatial)*

Functional = Domain Plan (Structural & Arch.) + Domain Decision (Structural & Arch.) + Domain Evaluation (Structural & Arch.)

Action = Calculation + Sketch

Therefore, the sum of the functions of planning, action and evaluation equals the total problem solving time. Also, the sum of the two domain subjects (spatial and functional) and of process is equal to the total problem solving time. The sum of spatial, functional, and action is equal to the subject domain time.

3 Analysis of Protocol Data

The problem solving sessions of the experts are discussed below. For each expert, a narrative of each problem solution is presented, a quantification of the solution process for each problem is shown, and the responses to the questions at the end of the questionnaire (Appendix **B)** is provided.

3.1. Expert One

The first expert is Professor IJ. Oppenheim. He is an Associate Professor in the Departments of Civil Engineering and Architecture at Carnegie Mellon University with 15 years of teaching experience. He teaches courses in structural design at both graduate and undergraduate levels in Civil Engineering and Architecture. His experience derives from developing courses in steel and concrete design and his studies into the response of structural systems to earthquake motions. As the first expert to perform the knowledge acquisition process, his solutions verified that the information in the problem statements was complete.

Although he does not design structural systems on a daily basis as do the other experts, his results are shown for comparison.

Activity Times		Time (min.sec)
Input		**3.00**
Process Plan		**12.00**
Domain Plan		**10.15**
Structural	**2.45**	
Spatial	**7.30**	
Architectural	**0.00**	
Action		**22.35**
Calculation	**20.45**	
Sketch	**1.50**	
Process Decision		**0.00**
Domain Decision		**4.05**
Structural	**3.30**	
Spatial	**0.35**	
Architectural	**0.00**	
Process Evaluation		**1.55**
Domain Evaluation		**19.25**
Structural	**13.20**	
Spatial	**2.40**	
Architectural	**3.25**	
Total Time		**73.15**

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	**25.15**	34
Action	**22.35**	31
Evaluation	**25.25**	35

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		**16.55**		23
Domain		**56.20**		77
Spatial	**10.45**		15	
Functional	**23.00**		31	
Action	**22.35**		31	

Table 3-1: Expert 1 - Problem 1

Professor Oppenheim's problem statement included design for earthquake loads. One can see from the transcript (Appendix B) that some of his computation time was spent in understanding the earthquake codes. The earthquake provision was removed from the problem statements given to the other experts, using the provision that wind loading was the dominate design for lateral loads, so that all buildings would be designed to the same standard and that comparisons between wind and earthquake lateral load magnitudes would not have to be performed.

Professor Oppenheim solved Problem 1 using a steel structural framing system. He did not think concrete was a viable alternative due to the length of time for construction. He investigated both a trussed lateral framing system and a moment resisting frame system. After calculating overturning moments and doing a simple portal analysis, he found that two four-bay rigid frames could be used in the east-west direction and five one-bay braced frames in the north-south direction. He placed the east-west rigid frames on the perimeter of the building and located the north-south braced frames in the interior by placing three of the braced frames in the core area and the other two at column lines located between the core and the perimeter.

As seen from Table 3-1, the planning, action, and evaluation times for the solution to this problem were equally split Approximately triple the time was spent on domain related activities as compared to process related activities. A graphical display of the sequencing of the activities is shown in Figure 3-1. This figure shows that the planning activities became shorter in duration and the evaluation activities longer as time progressed. There appear two times at which sketching was perfonned: the first towards the middle of the problem when trying to determine locations of structural framing, and the second to show the results of his solution. He also referred to these sketches to select dimensions for his calculations.

Problem 2 was performed in nearly half the time of Problem 1 (Table 3-2). The planning times for the second problem were nearly one-third of those of Problem 1 and the action times were nearly one-half. The reason for these time reductions was the direct use of calculations performed in Problem 1, and only referenced in the second problem. To justify the use of those calculations, the evaluation time in the second problem increase over the first problem. Table 3-2 shows that the time spent on the process was one-half, as the two buildings were very similar so the same problem solving procedure was used. This left more time for investigation of the domain related activities.

Figure 3-2 shows that more time was spent on the structural aspects of the problem which is also verified by the times in the tables. The spatial problems were solved in the same manner as the first problem and thus relatively little time was delegated to these activities. The final solution that the expert obtained involved a direct scale-up from the first solution. In the east-west direction four rigid frames were needed each four bays long, and in the north south direction nine braced bays were required. The extra length of the building provided room for the placement of these braced bays in the interior of the building with the majority located in the cores. Another alternative suggested by Prof. Oppenheim was to use only two rigid frames in the east-west direction, but being six or seven bays in length rather than the four bay length. Then in the north-south direction he suggested using two 100' deep trusses on the perimeter. This would give an architectural effect to the exterior of the building while providing the lateral load resistance.

The third problem presented difficulty to Professor Oppenheim. He indicated that he had never attempted designing anything with this kind of floor plan. Although the total time for the problem solution fell between his other two problem durations, the design obtained at the end of the problem solution was much less detailed. As seen from Table 3-3, the sketching time was much longer than for the previous problems. While looking for acceptable framing solutions, he kept saying that potential solutions "did not look right". Obviously the sketches provided input for the acceptance or rejection of various structural alternatives. The action time shown in Table 3-3 reflects the level of detail in the final solution as being

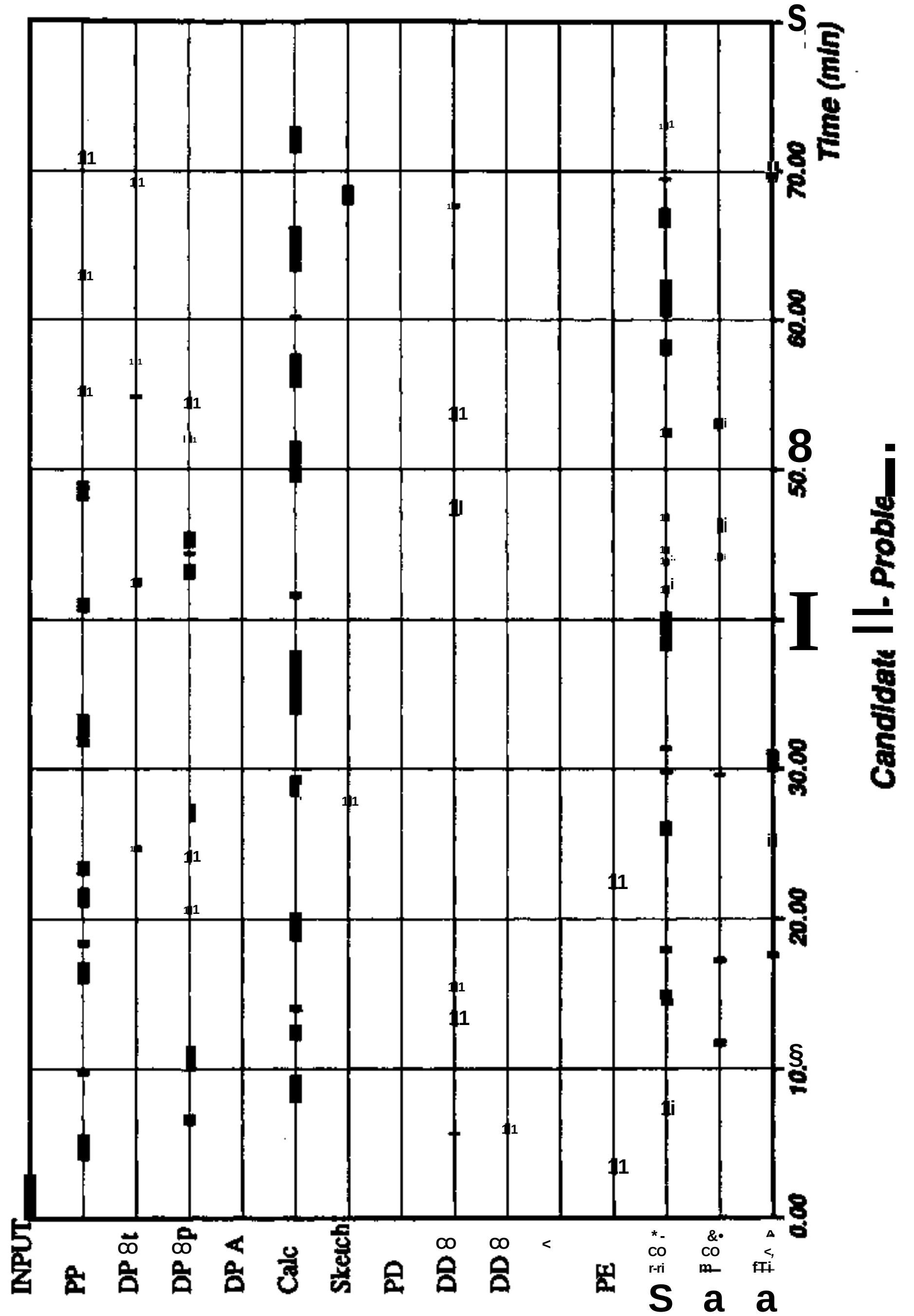

Figure 3-1: Activity Plot vs. Time for Expat 1 - Problem 1

less than the previous two problems. The table shows that the planning time and evaluation time occupied a higher percentage of the problem solution. Also, the amount of time spent with the spatial aspects of the problem were nearly twice as long as the previous problems. This indicates that the unfamiliar layout of the building presented problems for his solution techniques or at least did not provide him with the opportunity to use spatial solutions of designs he had seen previously. Figure 3-3 shows the proportionally

Activity Times		Time (min^ec)
Input		1.15
Process Plan		**2.40**
Domain Plan		6.30
Structural	**4.20**	
Spatial	1.10	
Architectural	0.00	
Action		10.30
Calculation	10.10	
Sketch	0.20	
Process Decision		0.15
Domain Decision		3.30
Structural	1.55	
Spatial	1.00	
Architectural	0.35	
Process Evaluation		0.00
Domain Evaluation		13.40
Structural	10.35	
Spatial	1.55	
Architectural	1.10	
Total Time		38.20

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	10.25	27
Action	10.30	27
Evaluation	17.25	46

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		4.10		11
Domain		34.10		89
Spatial	5.05		13	
Functional	18.35		49	
Action	10.30		27	

Table 3-2: Expert 1 - Problem 2

larger **amount** of time spent in the spatial and structural planning and evaluation activities. Many of the evaluation activities were followed by a planning activity as he sought new solutions to the problem.

The solutions presented for Problem 3 were described in terms of the two towers. For the fifteen story tower, five interior braced bays or ten perimeter braced bays were suggested. Alternately, two rigid frames of five bay lengths or four rigid frames of three bay lengths could be used. As the tower is square in plan either solution would work in either direction. For the twenty-five story tower the same solutions were presented but the number of braced bays was increased to seven and the number of rigid frames was three

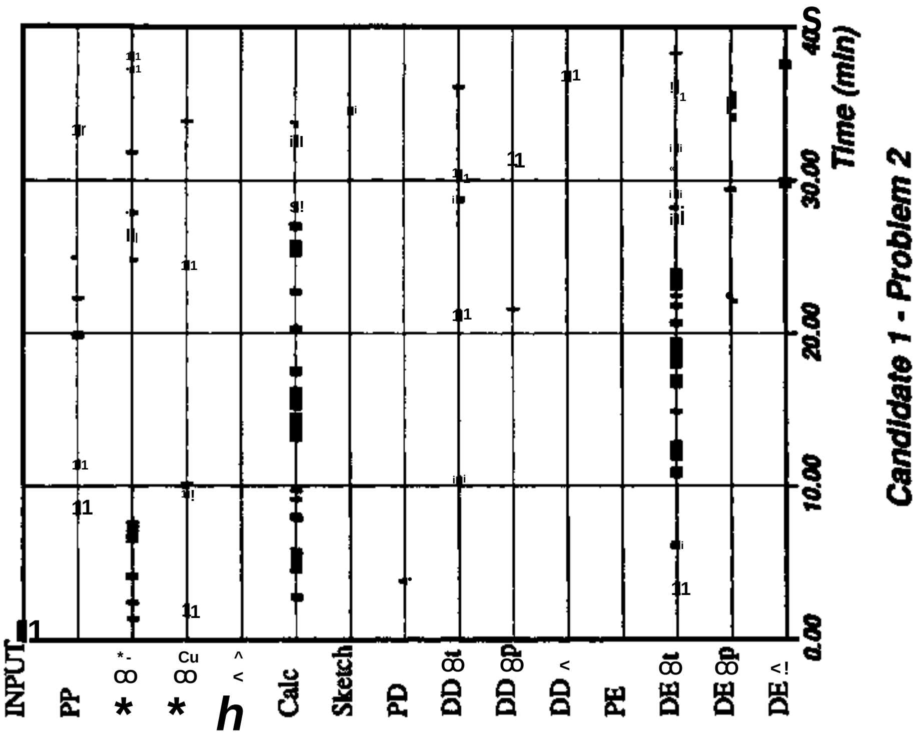

Figure 3-2: Activity Plot vs. Time for Expert 1 - Problem 2

five bay frames. One final idea that Professor Oppenheim suggested was using shear walls or rigid frames on the perimeter (the 200' perimeter sides) and reducing the length of shear wall or rigid frame towards the top of the building as needed. This would present an "interesting" architectural effect over the height of the building.

The responses to the questions asked of him following the problem solution can be found in Appendix B. His answers reflected the fact that increasing the scale (plan) of the building provides many more locations for structural placement and at extremes there are many possible places to locate a few structural frames. The determination as to which of these locations would be better would be difficult He sees the material selection of the building as occurring early in the design process and determined according to availability, speed of construction, and local contractor strengths. Architectural effects may also determine the material selection. He views the complexity of geometry within a building as being the most significant aspect to the problem solving process. The more complex the building geometry becomes, the more difficult and complex everything else in the building becomes.

3.2. Expert Two

The second expert is Housh Rahimzadeh, head of the structural engineering department for John Portman & Associates in Atlanta, Georgia. John Portman & Associates is an international architectural engineering firm which has designed many buildings in Atlanta, New York City, San Francisco, and Singapore. Mr. Rahimzadeh has 24 years experience as a structural engineer, the last 15 years with John

Activity Times		Time (min^ec)
Input		1.30
Process Plan		2.50
Domain Plan		10.20
Structural	5.25	
Spatial	4.55	
Architectural	0.00	
Action		4.55
Calculation	2.25	
Sketch	2.30	
Process Decision		0.10
Domain Decision		7.10
Structural	5.45	
Spatial	1.25	
Architectural	0.00	
Process Evaluation		1.10
Domain Evaluation		15.40
Structural	6.50	
Spatial	5.30	
Architectural	3.20	
Total Time		43.45

Summary by Function

Function	Time (min.sec)	% of Total Time
Planning	14.40	34
Action	4.55	11
Evaluation	24.10	55

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		5.40		13
Domain		38.05		87
Spatial	11.50		27	
Functional	21.20		49	
Action	4.55		11	

Table 3-3: Expert 1 - Problem 3

Portman & Associates. He holds a Bachelor's and Master's degree in civil engineering and has professional registration in several states. His experience has taken him to most of the major cities in the United States as well as southeast Asia.

The first problem was performed in less than a half an hour as shown in Table 3-4. As summarized in the table, Mr. Rahimzadeh spent half of his time evaluating the problem (most of the evaluation was from a structural viewpoint) and the remaining time was split almost evenly between planning and action. As shown in the Summary by Subject of Table 3-4 the vast majority of the time was spent in the domain areas

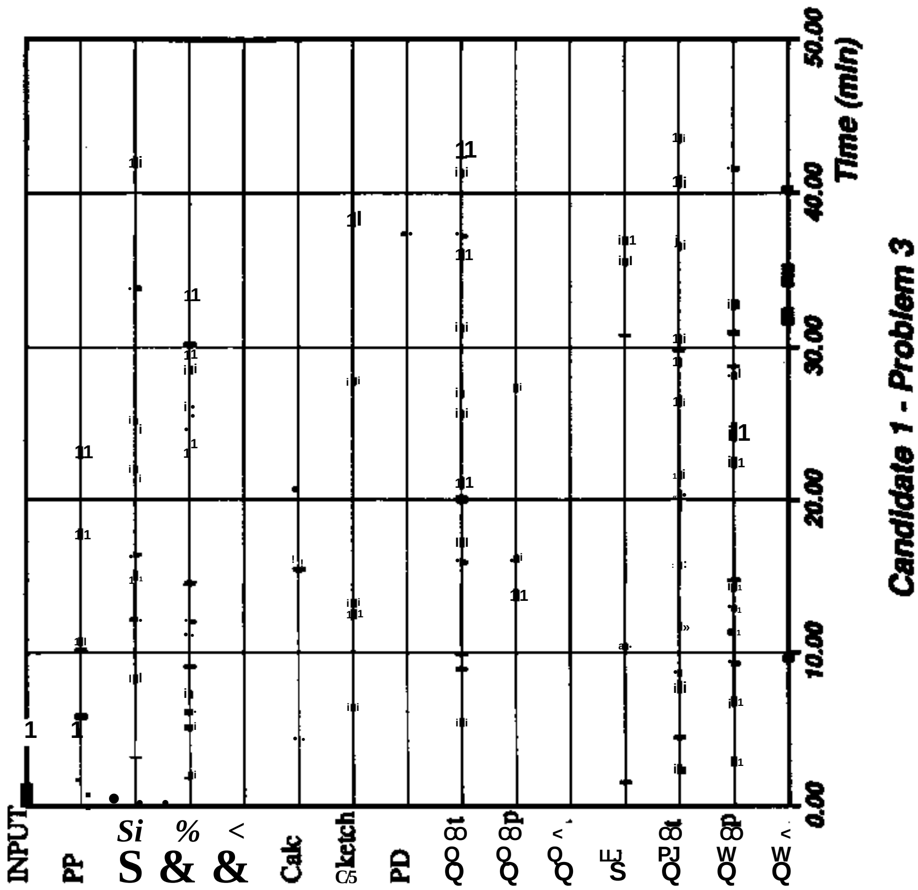

Figure 3-3: Activity Plot vs. Time *for* Expert 1 - Problem 3

of problem solving. The simplicity of the building presented a straightforward solution process and little time was spent planning or evaluating the process. Figure 3-4 shows that the planning activities occurred during the first half of the problem solution while evaluation was more prominent during the last two-thirds of the problem. The figure also shows much more time spent in decision activities than for the first expert.

During the problem solution, he presented solutions for both a concrete and steel alternative and detailed a preliminary foundation for the building. He did not consider this building "tall" as the aspect ratio is low (1.8). The concrete and steel alternatives both use rigid framing, as he thought this type of structural framing solution yields more flexibility to the architect and owner. He also indicated preliminary member sizes for typical columns, main beams, and floor beams. His solution process began by presenting desired goals or requirements and then attempting to find solutions that satisfied these goals. He located a column grid that provides six bays in the east-west direction and three bays in the north-south direction as he tried to meet a goal of 30 foot bays, a dimension he considers "most economical*'. He placed a moment resisting frame on the perimeter in the east-west direction as he felt that this location has less of an impact on the interior of the building. The north-south direction also used moment-resisting frames at each of the column lines except for the column line located in the center of the core. The column lines and frame types

Activity Times		Time (min^ec)
Input		1.25
Process Plan		1.20
Domain Plan		3.15
Structural	1.25	
Spatial	1.40	
Architectural	0.10	
Action		7.20
Calculation	6.50	
Sketch	0.30	
Process Decision		0.20
Domain Decision		8.35
Structural	7.45	
Spatial	0.50	
Architectural	0.00	
Process Evaluation		1.35
Domain Evaluation		3.40
Structural	2.40	
Spatial	1.00	
Architectural	0.00	
Total Time		27.30

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	6.00	22
Action	7.20	27
Evaluation	14.10	51

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		4.40		17
Domain		22.50		83
Spatial	3.30		13	
Functional	12.00		43	
Action	7.20		27	

Table 3-4: Expert 2 - Problem 1

remained in the same locations for both the concrete and the steel alternates. The slab thickness for the building was chosen at 4.5 inches based upon fire code requirements. The sizes for concrete beams were selected from experience and the columns were selected and verified by calculations. For the steel alternative, the beam depths are selected from experience and then their weight chosen from AISC tables [AISC 80]. At the end of the exercise, Mr. Rahimzadeh said that the solution has identified the major structural elements so that now the architect can continue laying out the floor plan.

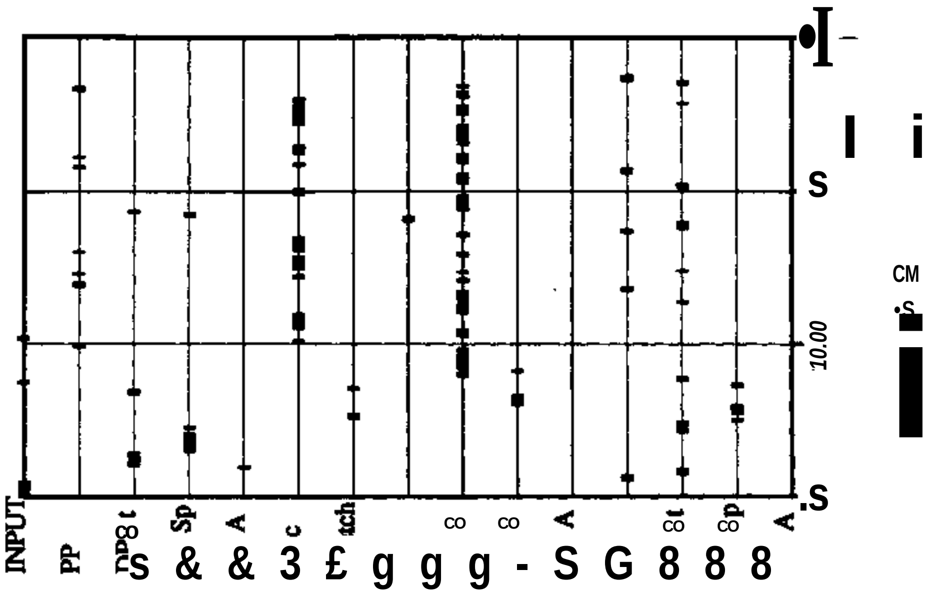

Figure 3-4: Activity Plot vs. Time for Expert 2 - Problem 1

The solution for the second problem required a little more than fifty minutes for Mr. Rahimzadeh (Table 3-5). Despite the time being nearly twice as long for the solution of Problem 2 as compared to Problem 1, the percentages of time spent planning, acting, and evaluating the problem are nearly identical as shown in the Summary by Function of Tables 3-4 and 3-5. Also the times spent performing process activities versus domain activities are nearly the same as seen in the Summary by Subject of the same tables. These comparisons suggest that the shape of the building may have governed the overall design process, and because the two problems are so similar (only there height and length differ) the solution processes are alike. Figure 3-5 shows the large amount of decision activities as did Figure 3-4 for the first problem. The timing of the planning and evaluation activities are very similar to Problem 1. For many of the activities, there is a close resemblance in the number of times each activity was performed and in the time of occurrence of the activity. This similarity supports a similar problem solving approach for Problems 1 and 2.

Like Problem 1, Problem 2 was solved for both a concrete and steel alternate. Preliminary foundations were designed for both options. The solutions to this problem involved moment resisting frames in the east-west direction and a combination of moment resisting frames and bracing or shear walls in the north-south direction. The combination of the two structural framing types in the north-south direction is chosen for "economics". He developed a column spacing using the same goal as in Problem 1 so as to achieve 30 foot bay dimensions and drew a scaled sketch of the building envelope so he could "see it better". This layout resulted in the same spacing as Problem 1 in the north-south direction providing three bays, and ten bays in the east-west direction each of thirty feet. Although the aspect ratio for this building is higher than the first building (3.6 vs. 1.8) he was very comfortable that a good solution could be achieved.

Activity Times		Time (min^ec)
Input		1.15
Process Plan		3.55
Domain Plan		6.30
Structural	4.35	
Spatial	1.35	
Architectural	0.20	
Action		12.40
Calculation	10.15	
Sketch	2.25	
Process Decision		1.15
Domain Decision		12.25
Structural	11.20	
Spatial	1.00	
Architectural	0.05	
Process Evaluation		3.30
Domain Evaluation		9.45
Structural	9.30	
Spatial	0.00	
Architectural	0.15	
Total Time		51.15

Summary **by Function**

Function	Time (min^ec)	% of Total Time
Planning	11.40	23
Action	12.40	25
Evaluation	26.55	52

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		9.55		19
Domain		41.20		81
Spatial	2.35		5	
Functional	26.05		51	
Action	12.40		25	

Table 3-5: Expert 2 - Problem 2

Mr. Rahimzadeh commented that his solution provides initial member sizes that would be used in a two dimensional computer analysis of the north-south system, since it would be difficult to accurately predicate the contributions of the braced or shear wall systems in combination with the frame action. To obtain the initial sizes of the members for this analysis he used only the gravity loads. The frames in the north-south direction were placed at nine of the eleven locations; the column line at the middle of each core was not used for lateral framing. He chose the depth of his beams from experience based on mechanical HVAC considerations and then chose a weight that will be structurally acceptable. He indicated that in many

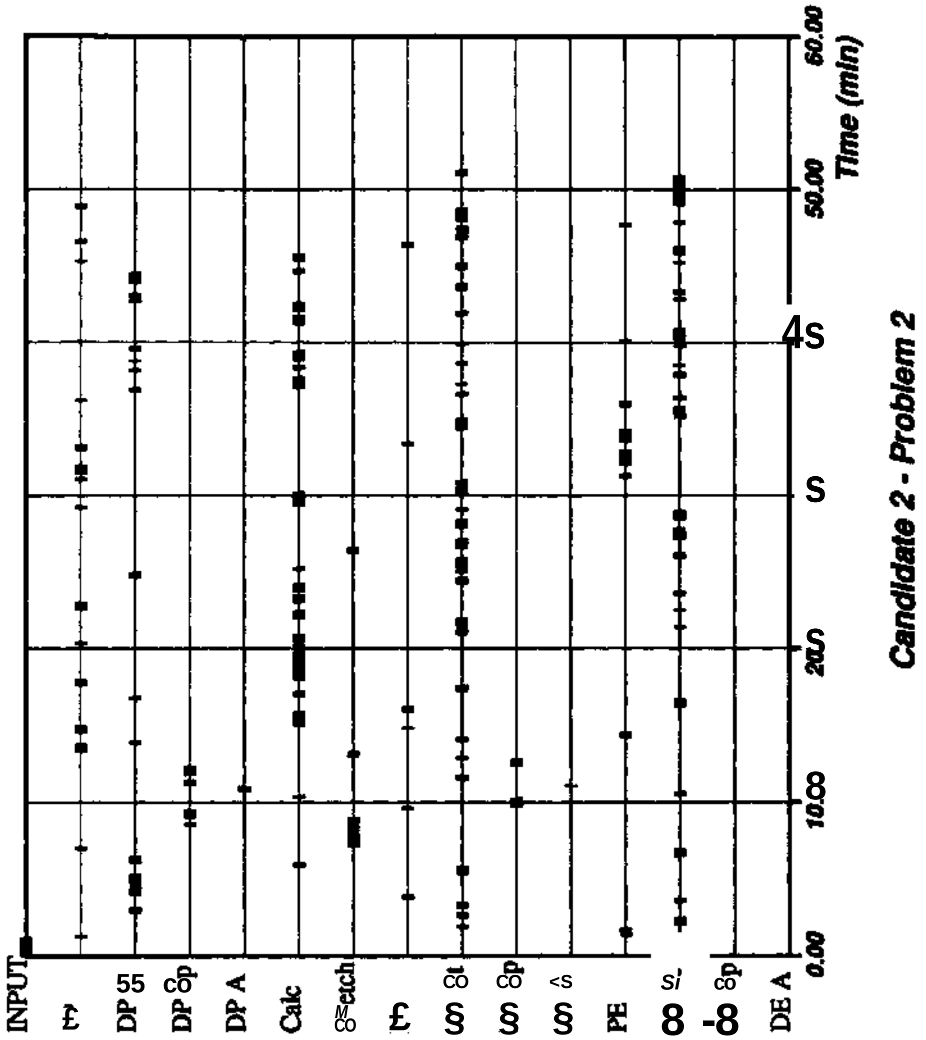

Figure 3-5: Activity Plot vs. Time for Expert 2 - Problem 2

situations the required penetrations of the main beams for HVAC ducts dictates the depths of those beams. The ducts are usually ten or eleven inches deep and he likes to keep at least three or four inches between the duct and the bottom flange. As the ducts go under the floor beams before penetrating the main beams, the depth of the main beams are determined by the depth of the floor beams plus approximately fifteen inches. The sizes of the beams and columns were selected from the AISC [AISC 80] tables for the steel alternate, and from the CRSI Handbook [CSI 75] for the concrete alternate. Mr. Rahimzadeh also considered whether the building should be designed with an expansion joint due to the 300 foot length. After some evaluation of past jobs, he decided that the building could be designed to handle the thermal loads rather than installing an expansion joint

Mr. Rahimzadeh developed a preliminary solution for parts a and b of Problem 3 in a little over an hour (Table 3-6). This solution provided preliminary sizing and placement for steel and concrete alternatives to part a and a steel alternative for part b. Additionally, he developed a preliminary foundation design for

Activity Times		Time (min«sec)
Input		2.10
Process Plan		2.20
Domain Plan		8.40
Structural	6.00	
Spatial	2.40	
Architectural	0.00	
Action		21.00
Calculation	17.15	
Sketch	3.45	
Process Decision		2.25
Domain Decision		14.00
Structural	10.50	
Spatial	3.10	
Architectural	0.00	
Process Evaluation		2.25
Domain Evaluation		15.25
Structural	10.25	
Spatial	4.45	
Architectural	0.15	
Total Time		68.25

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	13.10	19
Action	21.00	31
Evaluation	34.15	50

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		9.20		14
Domain		59.05		86
Spatial	10.35		15	
Functional	27.30		40	
Action	21.00		31	

Table 3-6: Expert 2 - Problem 3

both alternatives. Despite the different building shape, the percentage of time that he used for planning the problem, performing calculations, and evaluating the problem still is very close to the previous two problems as shown in Table 3-6. The percentage of time spent performing process versus domain activities is also very similar. The distribution of the domain activities are similar to the previous two problems, but more time was spent in this problem in the calculation and sketching activities (the action function shown in Table 3-6). Figure 3-6 shows a pattern similar to the previous problems performed by Mr. Rahimzadeh. He performed a lot of decision activities and there is a fairly even distribution of planning and evaluation

activities throughout the problem solution. The increase in calculation time can be seen in this figure and is predominantly located during the middle of the time frame.

When Mr. Rahimzadeh was first presented Problem 3, he immediately commented that this problem was interesting. The spatial arrangement of two towers and their intersection provided a challenge and the area of intersection between the two towers was an "interesting area". For part a of this problem, the entire building is office space. For this type of facility he designed both a concrete and steel alternate. Each of these alternates used only a moment resisting frame as he said that the height of this building was right at the edge of providing full capability of lateral support Additionally, the building looked "very stiff[9] to him and has a very low aspect ratio (1.S) even when considering only the plan dimensions of an individual tower. This aspect ratio would be lower if calculations used the entire base dimension at the intersection of the towers. Again he drew a sketch to scale so that he could locate the columns within the building envelope. He chose a column spacing of 33'-4" to give six uniform bays along the two hundred feet perimeter. This spacing was the same in both directions as the building is symmetric in plan. The number of bays and the length of the frame action allowed him to speculate that the design of the members would be based on gravity loads and not on lateral load. He sized the columns, main beams, and floor beams as he did in the previous problems.

For part b of Problem 3 an atrium having dimensions of one hundred feet on a side is located in the lower five floors of the fifteen-story tower. Because of the dimensions of this atrium, the column spacing for the building had to be changed, as there needed to be columns along the edge of the atrium to pick up the load that was transferred above the atrium. Mr. Rahimzadeh chose to use a 25 foot column spacing around the atrium and in the lower tower. He wanted to remain with the previous spacing for the other tower. It was not until the end of the problem that he realized the 25 foot spacing would need to be carried between the towers and effectively cover all but a very small portion of the floor plan. With this realization, he chose to use the 25 foot spacing throughout the building. The presence of the atrium seemed to attract his attention and the details about the rest of the building were secondary (presumably because he knew that a solution very similar to the one for part a could be used in the areas not effected by the atrium and that the atrium was "interesting"). He chose to only use a steel alternative for the second part of the problem as the construction shoring requirements for the atrium area using concrete would have been very expensive. To transfer the load at the top of the atrium, Mr. Rahimzadeh decided to use a Vierendeel truss system. Because of this truss, the analysis around the atrium would be very difficult to perform by hand. He decided that he would not come up with member sizes in this area; instead he would take a day to perform a computer analysis of the area and "get good numbers".

After completing the solutions to the three design problems, Mr. Rahimzadeh answered the questions shown at the end of Appendix A. While his responses to these questions can be found in Appendix B, a summary is provided here.

Concerning issues of building scale, Mr. Rahimzadeh indicates that the height and aspect ratio are the two most important parameter? of the building. As long as an acceptable aspect ratio can be achieved, then a feasible structural solution can be obtained. He indicated that an aspect ratio greater than 6 could cause problems especially in seismic zones or locations with large lateral forces. He also indicated that he likes

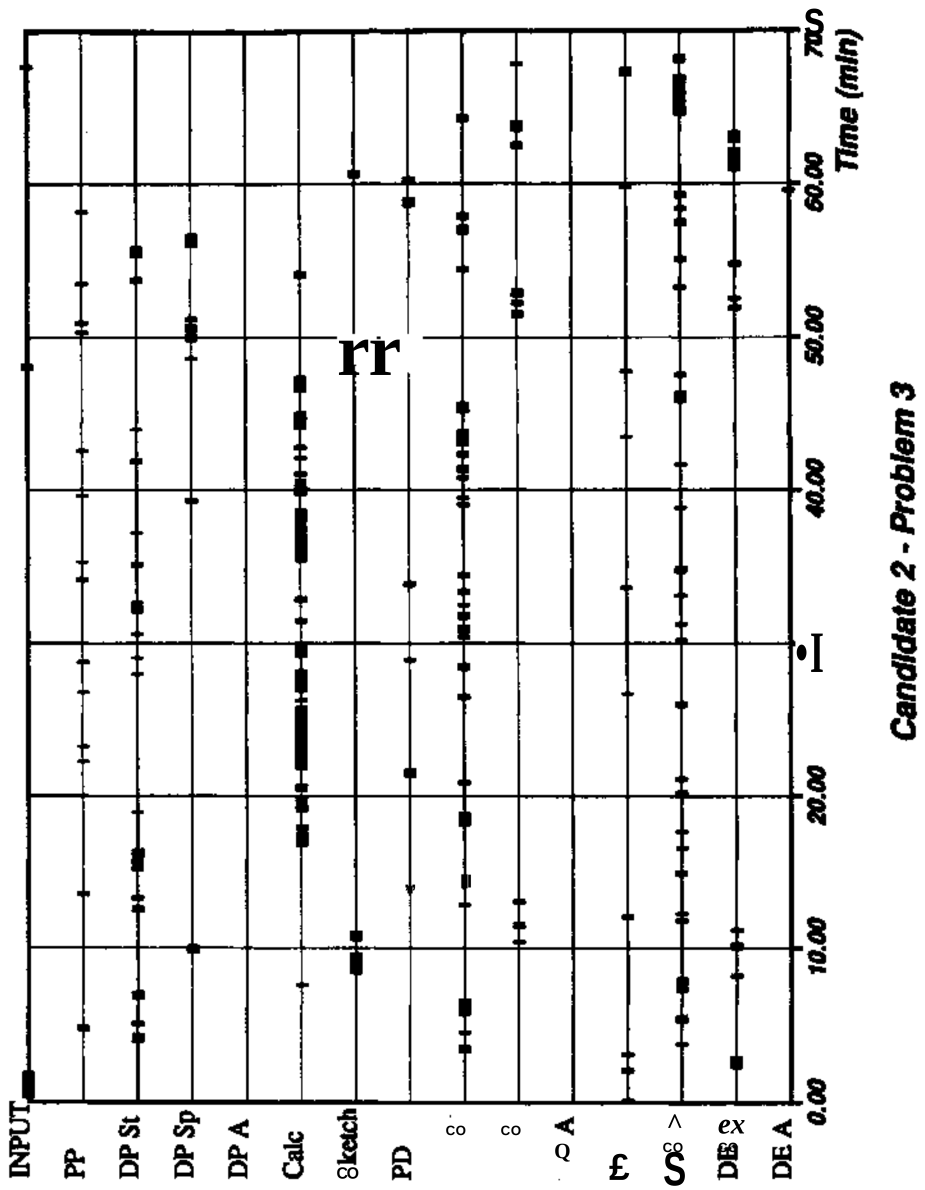

Figure 3-6: Activity Plot vs. Time for Expert 2 - Problem 3

to maintain a drift ratio of $\frac{h}{500}$ as a minimum, so that the tenants do not suffer comfort problems with building movement

The design process used at John Portman & Associates includes the structural engineer from the very beginning of the design process. The engineer looks at the site size, the floor plates and has input to all of the decisions. In his opinion, the process pays "good dividends at the end as everyone provides lots of input to the process and both parties benefit from the interaction". As soon as the initial decisions are made concerning height and shape of the building, the structural material is selected. The sooner the material is chosen the better, because "people can work toward a goal". The material is chosen based upon economic considerations, the building layout including the spans and height, and the location of the building. The structure is usually one third of the construction cost, so economic considerations are a large part of the decision. Certain building layouts also provide good material choices. For example, hotels are "a natural" for concrete as the partitions between rooms provide ample locations for shear walls, unless code restrictions arise due to seismic loads. Also concrete is better for some buildings where there will not be a false ceiling as its appearance is better than steel covered with fireproofing material.

Finally, he believes that geometry is a very important part of the design process. The more complex the geometry of the building, the more difficult is the design and construction. He also says that one has to very careful when making design assumptions about structural behavior with complex geometry. When making simplifications for preliminary design, the results can be very different from the results obtained from detailed design which considers the complex geometry. Without computer analysis tools, complex geometry would be a major problem in the solution process.

33. Expert Three

Expert three is Dennis Roth, owner and principal of Roth and Associates, structural engineers in Pittsburgh, Pennsylvania. He has been a structural engineer for the last 13 years and has Bachelor's and Master's degrees in civil engineering. During the last ten years, he has worked on approximately 1000 different projects. The tallest building he has designed is twenty-three stories and the types of buildings range from family dwellings to tall apartment buildings. He has developed structures using steel, concrete, and timber. Working as a consultant, most of his clients are architects and not the owners of a proposed facility.

Mr. Roth approached the solution to the design problems differently than the two other experts. He looked at them from a broader perspective and did not give any details of member sizes. His solutions contained information about what factors are important to the design process for the given problem and how he would go about choosing and locating a structural system for the building.

Problem 1 was completed in just under thirty minutes as shown in Table 3-7. This table shows that little time was spent in the action areas, but instead the time was spent in planning and evaluating different potential solutions. The functional summary in the table also shows that the times for planning and evaluation took roughly equal amounts of the problem time. The time was split equally between process and domain subjects as shown in the subject summary. Of the domain related activities, the functional aspects (those pertaining to structural and architectural activities) were performed nearly twice as often as the spatial aspects. This ratio is similar to the other experts for Problem 1. Figure 3-7 shows the emphasis of planning and evaluation activities. Relatively few decision activities were performed as compared to Mr. Rahimzadeh.

The solution to Problem 1 involves many different ideas that should be investigated before a structural system is chosen. Mr. Roth would want to know who the owner and architect is for the project as well as the *'building's constraints". As a consultant, these issues are probably information that he normally has at

Activity Times		Time (min^ec)
Input		4 .45
Process Plan		5 .05
Domain Plan		2 .10
Structural	1 .35	
Spatial	0 .35	
Architectural	0 .00	
Action		0 .20
Calculation	0 .20	
Sketch	0 .00	
Process Decision		0 .00
Domain Decision		1 .50
Structural	0 .20	
Spatial	1 .30	
Architectural	0 .00	
Process Evaluation		4 .20
Domain Evaluation		10 .40
Structural	7 .10	
Spatial	3 .30	
Architectural	0 .00	
Total Time		29 .10

Summary by Function

Function	Time (min«sec)	% of Total Time
Planning	12 .00	41
Action	0 .20	1
Evaluation	16 .50	58

Summary by Subject

Subject		Time (min^ec)		% of Total Time
Process		14 .10		49
Domain		15 .00		51
Spatial	5 .35		19	
Functional	9 .05		31	
Action	0 .20		1	

Table 3-7: Expert 3 - Problem 1

his disposal and they form part of the solution. The information or constraints that he wants are questions such as whether there is a basement in the building, what does the building look like on the outside, is vibration a concern to the owner, and how did the dimensions of the building get selected. He also would like to have 30 foot bay dimensions, so would like to change the building envelope to 90' by 210'. If vibration is not a concern to the owner then perhaps open web joists can be used as they are inexpensive. If vibration is a concern than a better solution would be to have composite beams and deck. For this building, possible framing solutions could be shear walls, rigid frames, or braced frames. Braced frames would be

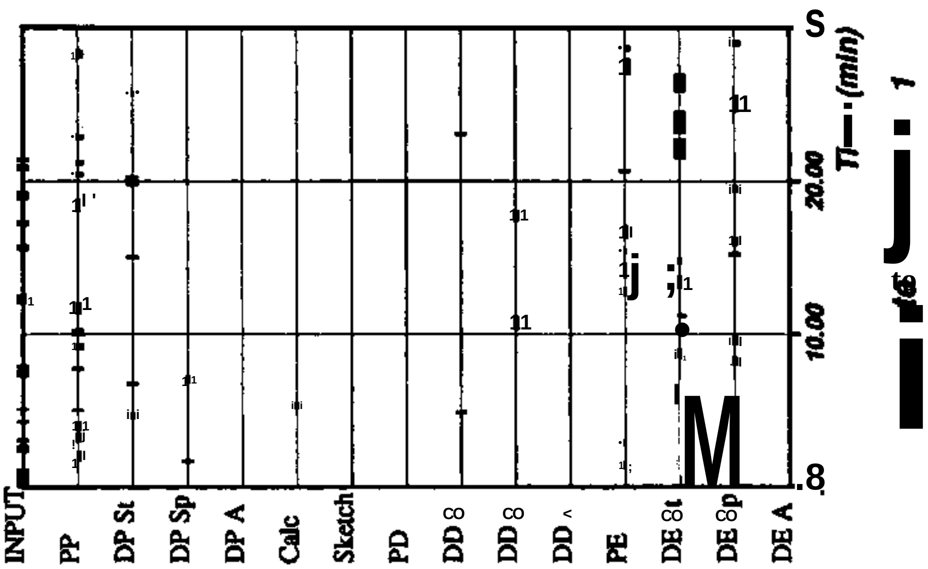

Figure 3-7: Activity Plot vs. Time for Expert 3 - Problem 1

the most economical solution, but he would not put bracing anywhere but in the core or perimeter since a flexible arrangement is desired. The cost of the structure is approximately thirty percent of the total cost of the project. The increase to a rigid frame from a braced frame would be approximately fifteen percent in the structural costs or an increase in the total project of roughly three to five percent. Some design issues can not be valued directly in dollars. The choice of bracing may limit the facade that can be chosen, or arrangements of interior space. It is difficult to assign a monetary value to these types of decisions. Before he could perform a preliminary design, he would need these issues resolved and then after a couple of days, he would have a decision for the structural framing selection.

The solution to Problem 2 went very rapidly and was completed in seven and a half minutes as shown in Table 3-8. Again the predominant activities were in planning and evaluation. In this problem, more of the time was spent in evaluation rather than in planning as in Problem 1. This is probably explained because the two problems are so similar. In fact one of the first statements Mr. Roth makes during Problem 2 is that all of the issues from Problem 1 apply to Problem 2. The percentage of time spent doing process activities versus domain activities is shown in Table 3-9 and is very similar to the first problem. Exactly half the time is spent in domain activities. Figure 3-9 shows that the number of activities and the duration of the problem solution were small.

Mr. Roth's comments concerning Problem 2 were mostly the same as the first problem. The biggest change between the two problems, he notes, is that the building is much taller and more slender. It has an aspect ratio of 3.5 and he thinks that it will be harder to control drift in this building. Because of the higher aspect ratio, a braced frame will be even more economical than a rigid frame. He located his columns every 30 foot in the long direction (east-west) and used the same spacing as Problem 1 in the short direction (thirty and thirty-five feet spacings). His only other comment concerning this building is that with the

Activity Times	Time (min.sec)	
Input		1.50
Process Plan		0.15
Domain Plan		1.45
Structural	1.35	
Spatial	0.10	
Architectural	0.00	
Action		0.30
Calculation	0.30	
Sketch	0.00	
Process Decision		0.00
Domain Decision		0.40
Structural	0.10	
Spatial	0.30	
Architectural	0.00	
Process Evaluation		1.40
Domain Evaluation		0.50
Structural	0.40	
Spatial	0.10	
Architectural	0.00	
Total Time		7.30

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	3.50	51
Action	0.30	7
Evaluation	3.10	42

Summary by Subject

Subject		Time (min.sec)		% of Total Time
Process		3.45		50
Domain		3.45		50
Spatial	0.50		11	
Functional	2.25		32	
Action	0.30		7	

Table 3-8: Expert 3 - Problem 2

mechanical floor located on the fifteenth story could be used to stiffen the building structurally to reduce the drift at the top of the building. He said, however, that reducing the drift by stiffening on the mechanical floor would be addressed on the second or third iteration of the design and not during preliminary design.

The solution for Problem 3 was discussed for nearly twenty minutes and the amount of time for the various activities can be seen in Table 3-9. As with the first two problems, he spent his time on Problem 3 in planning and evaluation. The table shows that the time was almost equal and follows the same ratio as for the previous problems. There was a change in the amount of time spent doing domain activities and

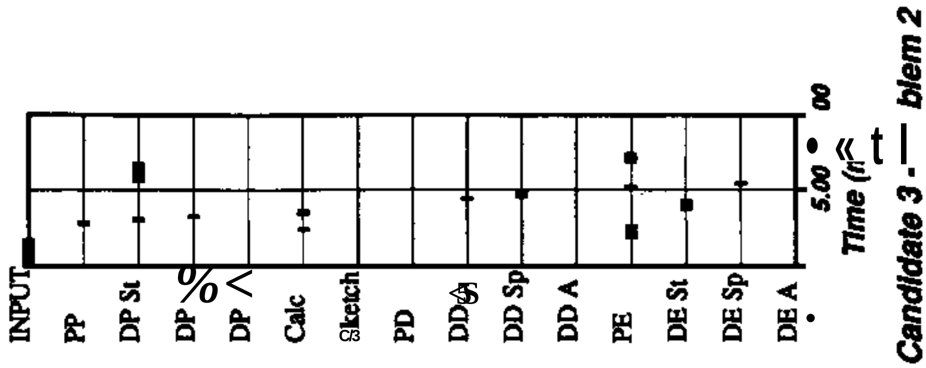

Figure 3-8: Activity Plot vs. Time for Expat 3 - Problem 2

process activities in problem three. Table 3-9 also shows that more time was spent in domain activities than in process activities and the majority of the domain time was spent in functional considerations. Figure 3-9 shows the timing of the activities and how the structural activities of planning and evaluation captured most of the expert's attention.

The solution for problem three involved a discussion of the issues requiring attention in the solution of the problem. When given the problem Mr. Roth said that this problem would be *'different" and is "much more interesting and challenging". He indicated that there are "lots of conflicting things between the two buildings" that have to be decided, such as whether the two buildings should be tied together or separated by an expansion joint He said that the core is too small and will change size and maybe location before a satisfactory solution is found. He indicated that a rigid frame would be satisfactory for the structural system and that it might be the only one acceptable to the architect When introducing the atrium into the problem, he saw problems with transferring the loads above the space to the perimeter. The corner of the one tower lands in the atrium area so he thought that the atrium may also move. However he thought that the problem was very interesting. He indicated that the more constrained an individual is, the more clever he can be developing a solution. He saw many different ideas for the atrium such as a huge *'monolith" column to support the roof and tower comer, or a multi-story truss at the top of the atrium that could provide various visual effects. The location of the atrium and core causes column location problems, but he saw possibilities for placing the columns on either thirty-three foot centers or twenty-five foot centers. As one last idea, Mr. Roth suggested that if the mechanical system for the building were on the fifteenth floor of the lower tower, then perhaps the floors above the atrium could be suspended from a big truss located in the mechanical area.

After finishing the problems, Mr. Roth answered the questions contained at the end of Appendix A. His answers are shown in Appendix B and are summarized here.

Scale of the building plays a role in several ways. When a building increases in size, the core area increases and that provides more room for structural placement More important is when the building changes in height rather than changes in plan. Sometimes when a building is small, the client may be on a

Activity Times		Time (min^ec)
Input		0.50
Process Plan		2.15
Domain Plan		6.10
Structural	3.55	
Spatial	2.15	
Architectural	0.00	
Action		0.00
Calculation	0.00	
Sketch	0.00	
Process Decision		0.10
Domain Decision		1.15
Structural	0.55	
Spatial	0.20	
Architectural	0.00	
Process Evaluation		2.55
Domain Evaluation		5.55
Structural	3.15	
Spatial	0.55	
Architectural	1.45	
Total Time		19.30

Summary by Function

Function	Time (min^ec)	% of Total Time
Planning	9.15	47
Action	0.00	0
Evaluation	10.15	53

Summary by Subject

Subject		Time (min*sec)		% of Total Time
Process		6.10		32
Domain		13.20		68
Spatial	3.30		18	
Functional	9.50		50	
Action	0.00		0	

Table 3-9: Expert 3 - Problem 3

tighter budget and thus the solutions available must reflect the limited cost. He thinks that a change in dimensions to accommodate thirty foot bays as being more important than deciding whether the building is 100'or200\

In his practice, he usually is a consultant to an architect Many times when the architect comes to him, a lot of the decisions have already been made. The columns have been placed, the floor to floor height selected, and the material chosen. It is then his job to design a system to fit this scheme. He would prefer to see much earlier involvement in the design process.

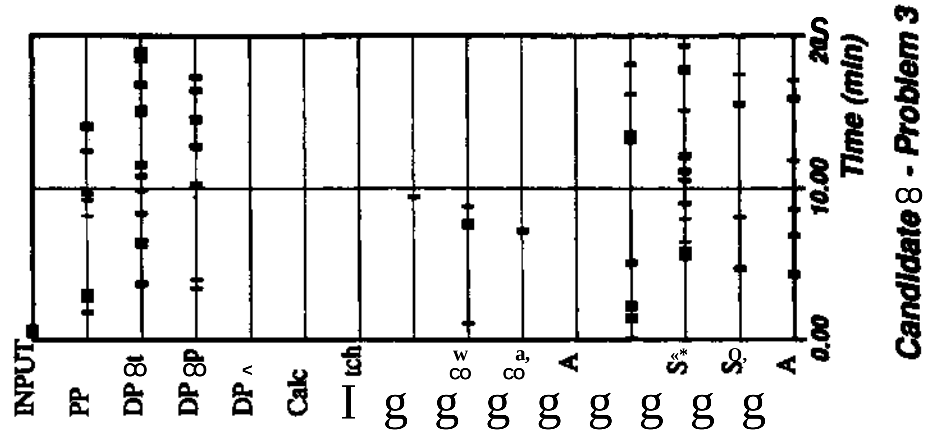

Figure 3-9: Activity Plot vs. Time *for* Expert 3 - Problem 3

The selection of the material for the structural system is made very early in the design process. However it is decided on by more than structural considerations. The architectural effect and HVAC issues must be included into the assessment of the selection. The location of the building is also an important parameter of the material choice. In the Pittsburgh area, most buildings are constructed with steel; in other parts of the country that is not necessarily the case.

4 Findings

Having presented the protocol data, several conclusions can be made. This section discusses comparisons between the experts as shown in the data, and some common traits of the design process. The discussion is related to the purposes outlined previously.

4.1. Comparisons of Protocol Data

Level of detail. The solutions the experts present for each of the problems vary substantially in the amount of detail provided. Mr. Rahimzadeh (Expert 2) provides the most complete preliminary design information. He spends time producing both steel and concrete alternates where he feels both materials are viable. He also provides preliminary designs for the foundations. Professor Oppenheim (Expert 1) provides a preliminary design for Problems 1 and 2 to the same level as Mr. Rahimzadeh for a steel alternate. In Problem 3, Professor Oppenheim discusses ideas for a potential solution, but does not provide details. The third expert, Mr. Roth, does not provide a preliminary design. He discusses the factors he deems important to the design and how those factors influence decisions he makes. He discusses various structural systems that could be possible to use for the current problem, but does not do any preliminary sizing or placement

Solution Time. Despite the difference in the content of the solutions presented, several comparisons can be made from the protocol data. The tables (such as 3-1 and 3-4) show the amount of time the experts use for each of the activities for a given problem. The strongest statement these tables show is the amount of time required by candidate one for action activities as compared to expert two (expert three is not compared as he did not produce any detailed design). The truest comparison comes from Problem 1 where the solution produced was of comparable detail. Expert one used much more time in calculation than Expert two. Problem 2 shows a closer amount of time between the experts, but it is pointed out that expert two produced a design for both concrete and steel in addition to the foundation, while expert one only produced a design for steel.

Problem 1

Function	% of Total Time		
	Expert 1	Expert 2	Expert 3
Planning	34	22	41
Action	31	27	1
Evaluation	35	51	58

Problem 2

Function	% of Total Time		
	Expert 1	Expert 2	Expert 3
Planning	27	23	51
Action	28	25	7
Evaluation	45	53	42

Problem 3

Function	% of Total Time		
	Expert 1	Expert 2	Expert 3
Planning	34	19	47
Action	11	31	0
Evaluation	55	50	53

Table 4-1: Summary by Function

Distribution of Time. The percentages of total time by function did not change much for a given expert between the three problems; that is, the percentages for planning, action, and evaluation are almost the same for an expert for each problem (Table 4-1). While there is no objective method for determining if a subject is **an** expert [Ullman 86], perhaps the quantitative differences between the times spent planning and evaluating versus time spent in the action part of problem solution for the three subjects of this study indicate traits that experts exhibit; that is, more time is spent planning and evaluating rather than acting. Support for this theory comes from the fact that the time spent in action activities in Problem 3 for Expert two increased over the previous problems. Additionally, the other experts did not produce a design for this problem, but only discuss options that they would consider. This seems to agree with the notion that experts exhibit "rules of thumb" or heuristics of good judgment that characterize "expert level" decision making and that they have short cut plans and evaluations of situations for solving problems [Harmon 85]. It would be very interesting to obtain information from one or two more experts to see if they exhibit the same ratios for the percentage of time spent planning, acting, and evaluating to verify this hypothesis.

Problem 1

Subject	% of Total Time Expert 1	Expert 2	Expert 3
Process	23	17	49
Domain	77	83	51
Spatial	15	13	19
Functional	31	44	31
Action	31	27	1

Problem 2

Subject	% of Total Time Expert 1	Expert 2	Expert 3
Process	11	19	50
Domain	89	81	50
Spatial	13	5	11
Functional	49	51	32
Action	27	25	7

Problem 3

Subject	% of Total Time Expert 1	Expert 2	Expert 3
Process	13	14	32
Domain	87	86	68
Spatial	27	15	18
Functional	49	40	50
Action	11	31	0

Table 4-2: Summary by Subject

The amount of time spent in process activities and domain activities for the three problems is nearly constant for a given expert. When looking at Table 4-2, the percentage of time that expert two spent on domain activities for each of the three problems is essentially the same. The percentages of time shown in this table indicate that Mr. Rahimzadeh's (Expert 2) protocol session provides useful information about the details of design which is indicated by the percentages of times being laiger for domain activities than process activities. Likewise, Mr. Roth (Expert 3) provides information about the process of design as shown by the large portion of time in the process activities. Mr. Roth's information includes investigating what concepts should be considered for a given design.

Use of previous information. The tables also show how each expert used previous information in a current problem. This is reflected in the times between Problems 1 and 2. Problem 2 was similar to Problem 1, only the building was longer and taller, thus creating a higher aspect ratio. Each expert used the similarities between the two buildings to his advantage by referencing previous calculations rather than redoing them. Experts one and three reduced the time for completion of Problem 2 substantially from

Problem 1. Expert two used more time for the overall solution to Problem 2 than he did for Problem 1. The extra time can be found in several places. First, he spent extra time in evaluation, explaining why he chose beam depth and then looked for a beam with that depth to satisfy the structural requirements. He also spent more calculation time in Problem 2 as the increased building height made member stresses closer to allowable code limits than in Problem 1. In essence, Problem 1 was so routine that he could produce a solution from experience and felt confident with the solution. However, for Problem 2, while he also produced a solution from experience, he felt compelled to verify that the solution would work.

General Observations. Several other observations can be made about the protocol data collected from the experts. Experts one and two were very particular about the sketches. Each wanted the sketch to be close to scale. These sketches were referred to at various times in the solution of the problem. They seemed to provide a reference point for the expert as to what was done and how everything fit together. It is difficult to say whether expert three would have been particular about the sketches as he did not draw any sketches. However, he did describe visual pictures of how systems fit together.

Mr. Rahimzadeh's session provides good information about preliminary design as previously shown in the tables. His solutions are very detailed and can be used to study the design process. The first two problems presented to him for solution were solved in a very similar and methodical manner. However the third problem was of interest to him and the two towers presented him a "challenge". The atrium captured his attention to a point where he spent most of the solution time discussing structural and architectural considerations around the atrium.

Mr. Roth's session provides information about planning the processes and global issues as verified in the tables. He discussed the solution process he would use and what issues needed to be resolved before he could develop a preliminary design. As a structural consultant to architects, Mr. Roth usually is given more information than these problems presented. Therefore, he wanted answers to these various issues before he felt comfortable developing a structural solution. Mr. Roth has served as an expert for several other knowledge acquisition projects, and it is possible that he was trying to present information for this exercise as he did for the other sessions.

4.2. Design Techniques

As shown in the protocols, all three experts clearly work in two dimensions and then compare the proposed structural solutions for the two primary directions when placing the systems in the building. The process usually involves performing preliminary design on the system that would be most difficult (usually the one parallel to the shortest side of the building) and locating it in the building first Then the other direction is studied and compatible systems are investigated. Thus the three-dimensional effects are handled by the selection of a compatible (both structurally and architecturally) structural system that is perpendicular to the first structural system. This method for handling three-dimensional effects of structural systems is currently used in HI-RISE [Maher 85], a system for performing preliminary structural design. Symmetry also is important to the experts. The designs are modified until the floor plans are nearly symmetric. Vertical symmetry is also desired so that loads from members can be carried directly to the foundation and not transferred.

The difference in employment reflects two types of involvement that structural engineers have in the building design process. The second expert is an engineer employed by an architectural-engineering firm and the third expert is a structural engineering consultant to various architects. The engineer from the architectural-engineering firm is involved in the design process very early, while the consultant usually participates much later. Experts two and three both suggest that a design process having early interaction by the engineer is necessary to achieve well-designed buildings. In this type of process, both architects and engineers can give input to the development of the building.

The experts in this study rely on drawing sketches of floor plans to "visualize" the placement of columns and structural systems within the buildings. They use the sketch for spatial planning, for showing and describing results, as analysis aids - that is to get dimensions for calculations, and to explain various situations (for example, the second expert used a sketch to explain the cutouts in structural steel for HVAC duct work). This dependency on sketches is reinforced by a study conducted by UUman where he lists six significant roles that sketches provide during problem solution [Ullman 86]. These roles are:

- An archive of geometric form;
- A method of communication between designers;
- A visual simulation of potential design ideas;
- An analysis tool;
- A completeness checker; and
- A form of "external memory" where the designer can record partial solutions to the problem.

Larkin and Simon also report that sketches are valuable to problem solution [Larkin 87]. They report that people focus attention on certain parts of a diagram. This focus of attention allows the retrieval of problem-relevant information from memory. A sketch can group together all information for a problem, thus avoiding large amounts of search when the same information is needed.

The uses for sketches found by Ullman are at least partially verified by the experts used in this study. Many of the activities labeled "Domain Planning /Spatial" involve the expert visually referencing a sketch. As Larkin and Simon explain, the expert is using the sketch to retrieve problem specific information.

The sketches provide useful information to the expert for the spatial planning process. Thus the sketch is important to the syntax of the proposed language. Items of particular spatial interest are corners of the building envelope and the corners and sides of the core. The placement of columns in these locations spawns the placement of the columns throughout the building. The placement of columns in the interior of the building is guided by the goal of 30 foot column spacing.

The experts handled the low floor to floor height (a spatial conflict) presented in the problems by maintaining a column spacing they desired and decided to have the architect increase the floor to floor height This low height was chosen to force the placement of columns within the interior of the building, but even with the increased floor to floor height, interior columns were needed. Clearly, the experts felt that a feasible solution could not be obtained with the floor to floor height presented and indicated that the only option was to increase this dimension.

The functional characteristics that are of importance to the experts are a combination of structural, architectural, and mechanical concerns. The structural properties of the building's chosen material dominates the various options used by the experts, but influences of HVAC duct placement, architectural influences and tenant requirements also are involved in locating and choosing structural systems. The structural properties of interest to the expert involve the classical engineering principles of structural mechanics such as bending moments, shear, and compression forces. However, the non-structural characteristics are also important. These include choosing a beam depth as required by HVAC penetration, choosing lateral structural systems which do not inhibit circulation within a building, choosing a system to allow the most flexibility in arrangement of tenant space, and systems that help make an architectural impression for the owner.

Wiecha reports that researchers have found evidence for a mixed approach to design of computer software [Wiecha 86]. Designers construct tool-kits of functions they feel will meet the needs of the problem and combine these functions together towards a finished system. The experts in this study clearly describe goals or objectives that a design must satisfy, and then very quickly seem to try various solutions and see if they work. The experts have a collection of what may be termed "partial solutions" from which to assemble new designs. As the expert acquires more expertise, this collection becomes richer and the amount of time used in action activities decreases as the planning and evaluation of these "partial solutions" becomes an increasingly dominant activity.

From the protocol data collected and the observations obtained from this data, the experts consider more than structural mechanics when designing structural systems for buildings. Their design process includes the use of sketches and previous information to arrive at a solution. They begin the design process by stating goals and then work from previous partial solutions to construct the final solution. One potential measure of an expert is the amount of information contained in the partial solutions. The more information that is contained in the partial solution, the better the chances of the person being an expert.

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A Questionnaire for Knowledge Acquisition

The following pages represent the questionnaire given to the experts when performing the knowledge acquisition for this research. There are accompanying VHS video tapes of each expert who took part in the process. Each expert was given the instruction sheet so that each was told the same pieces of information. Then the expat was given the problems, one at a time to perform a preliminary design.

Instructions

During the next several hours, I will be presenting you with several design scenarios. The design scenarios **are** highly idealized problems purposely made simple to explore design strategy. For each case, you are asked to develop a preliminary structural framing solution. Each solution involves describing the type of structural framing system chosen and its placement in the facility.

While you work on each problem, you are to think ALOUD. Verbalize all of your thoughts, no matter how insignificant or unrelated you may think the thoughts are. You do not have to explain your thoughts, just verbalize them. If you feel that you can not verbalize some thought, try using words such as Tm visualizing the connection between ..." and sketch it During your solution, feel free to use whatever books or materials you normally use and design by the most applicable code. The purpose of these problems is to record someone designing a structural framing system by their normal methods. Since you will be verbalizing your thoughts, the solution you develop will take longer than normal - do not let this bother you. I want to capture the process of design, not the speed of design.

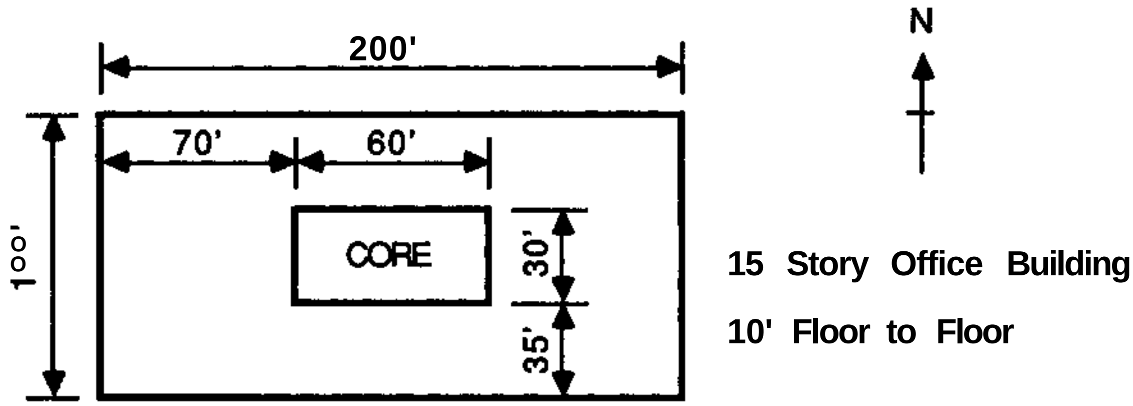
Your work should be done on the sketch pad provided. Ask me any questions you may have and remember THINK ALOUD.

Problem 1

Read this problem statement ALOUD.

A client has approached you with a sketch of a proposed office building shown in the figure below. The client has asked you to develop an efficient structural framing plan for this new building which will be located on his site in town. A geotechnical engineer has told your client that a good bearing strata is available over the entire site at a depth of 20 feet The mechanical equipment for the facility will be placed on the roof. Your design of the structural framing system should allow for a flexible office arrangement since the tenants for the building are not known. The live loads for this building are: a 100 psf gravity load; and a wind load of 40 psf. Wind load is the controlling lateral live load for this building.

Your work should be done on the sketch pad provided. Ask me any questions you have, and THINK ALOUD.

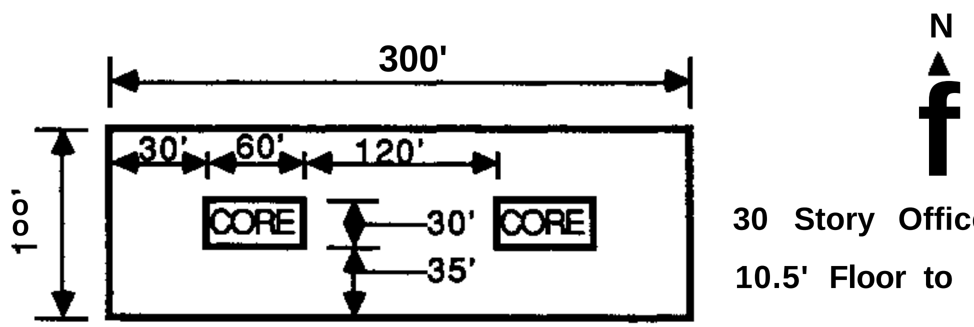


Problem 2

Read this problem statement ALOUD.

This problem is very similar to the previous one. You are asked to develop a structural framing plan for an office building with a floor plan shown below. The dimensions are all symmetric. Again, develop the structural framing system type and placement in this facility. In this facility, the mechanical equipment will be placed on the 15th floor. A geotechnical engineer has told your client that a good bearing strata is available over the entire site at a depth of 20 feet Your design of the structural framing system should allow for a flexible office arrangement since the tenants for the building are not known. The live loads for this building are: a 100 psf gravity load; and a wind load of 40 psf. Wind load is the controlling lateral live load for this building.

Your work should be done on the sketch pad provided. Ask me any questions you may have and remember THINK ALOUD.



30 Story Office Building

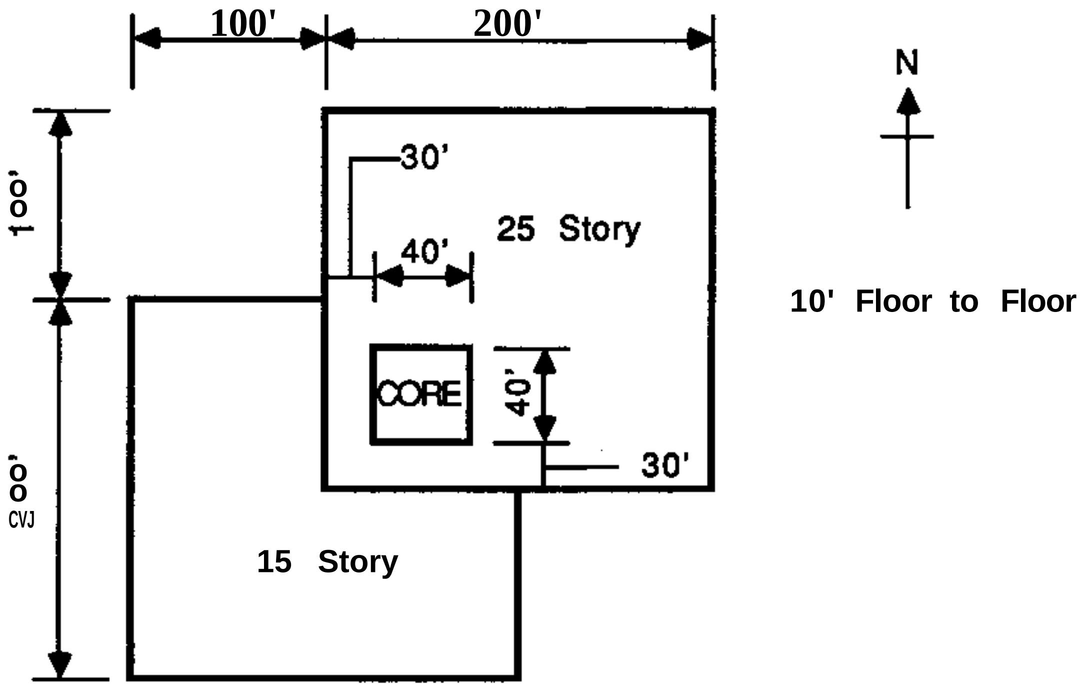
10.5' Floor to Floor

Problem 3

Read this problem statement ALOUD.

This problem differs from the previous problems in that there are two connected towers of differing height Circulation must be provided between the towers on every floor. Part A of this problem is to design the structural framing system for both towers containing office space. Part B of the problem is to design the framing system considering that the first 5 floors of the lower tower are commercial space and it is desirable to have an open atrium in the middle of this tower through the Sth floor having plan dimensions of 100' x 100'. A geotechnical engineer has told your client that a good bearing strata is available over the entire site at a depth of 20 feet Your design of the structural framing system should allow for a flexible office arrangement since the tenants for the building are not known. The live loads for this building are: a 100 psf gravity load; and a wind load of 40 psf. Wind load is the controlling lateral live load for this building.

Your work should be done on the sketch pad provided. Ask me any questions you may have and remember THINK ALOUD.



Discussion

Please respond to the following questions.

1. How important an issue is scale to developing a structural framing system? That is, if a building is 100' x 100' vs. 200' x 200' how would the design differ?
2. At what stage of the design process do you normally interact with the architect? Is the building already laid out room by room, or are you consulted either first by the client, or consulted initially by the architect?
3. How do designs for commercial space differ from office space?
4. At what stage do you converge on the material selection for the structural framing?
5. How does the complexity of the building geometry affect the design process?
6. For a building with complex geometry, do you first idealize the building into some simpler model for preliminary design?
7. During the design process, what problems seem to most often cause problems with the design?

B Transcripts of Knowledge Acquisition

The following pages show the transcripts of the knowledge acquisition process from the experts. Each expert is listed with summary transcripts of the three problems and their responses to the questions shown in the questionnaire.

The following symbol key describes the abbreviations for the activities the experts were classified as performing during the transcripts.

Symbol Key
to Activities

- **Input - Obtaining information about the problem**
- **Process Plan - Planning course of action for solving the problem**
- **Domain Plan - Planning type of action for solution of the problem. There are three types:**
    - **Architectural (/A) - Planning architectural concerns - functional feature**
    - **Spatial (/Sp) - Planning space allocation or placement - spatial feature**
    - **Structural (/St) - Planning structural concerns - functional feature**
- **Sketch - Drawing or viewing a drawing.**
- **Calculation - Performing numerical calculations, referencing previous numerical calculations, or performing table lookup operations.**
- **Process Decision - Deciding about the course of action to solve the problem.**
- **Domain Decision - Deciding about the solution of the problem. There are three types:**
    - **Architectural (/A) - Decision about architectural concerns - functional feature**
    - **Spatial (/Sp) - Decision about space allocation or placement - spatial feature**
    - **Structural (/St) - Decision about structural concerns - functional feature**
- **Process Evaluation - Evaluating the course of action taken or planned.**
- **Domain Evaluation - Evaluating the solution (proposed or possible) to the problem. There are three types:**
    - **Architectural (/A) - Evaluation about architectural concerns - functional feature**
    - **Spatial (/Sp) - Evaluation about space allocation or placement - spatial feature**
    - **Structural (/St) - Evaluation about structural concerns - functional feature**

B.I Expert 1

B.I.I Problem 1

Time h:nitn.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:03.00	Summarizes Problem Statement and Understands Problem	Process Evaluation
0:04.00	"Start collecting thoughts"	Process Plan
	"Flexible office, few columns, no walls Speed of construction"	Domain Plan /Sp/St/A
0:05.40	Chooses steel	Domain Decision /St
0:05.45	Looks at braced frames in core	Domain Decision /St/Sp
0:06.20	Tries placement of 2 @ 60' E-W and3@30'N-S	Domain Plan /Sp
0:07.00	Looks at these 2 choices - feels confident in E-W, unsure N-S	Domain Evaluation /St
0:07.50	Begins calculations in N-S	Calculation
0:08.50	Obtains overturning moment and figures induced axial load	
0:09.35	Needs gravity load	Process Plan
0:09.55	Needs framing grid - comes up with 35' pattern and sketches	Domain Plan /Sp Sketch
0:11.30	Evaluates span lengths of grid, fits nicely, looks at grid to see if looks good	Domain Evaluation /Sp
0:11.55	Calculates tributary area on core column - Estimates floor system weight	Calculation
0:12.55	Picks floor system of cone, slab on steel sheeting - 60psf	Domain Decision /St
0:13.50	Obtains dead load in column	Calculation
0:14.15	Evaluates dead load w/ induced load *'Not en ough safety factor"	Domain Evaluation /St
0:15.15	Can't use 3 braced frames in N-S	Domain Decision /St
0:15.45	Looks at alternatives	Process Plan
	Needs more braced bays - looks at grid	Domain Plan /Sp
0:17.05	Can get 5 braced bays & probably feasible but disadvantages - "cuts into office space"	Domain Evaluation /A/Sp

Time h:mm.ss	Description	Activity
0:17.45	Other disadvantage - might interfere with bracing in core for E-W	Domain Evaluation /St
0:18.10	Decides to look at E-W direction	Plan Process
0:18.35	Figures wind loads	Calculation
0:19.40	Figures number braced bays needed	
0:20.25	Needs 3 - 30' braced bays	Domain Plan /Sp
0:20.50	Looks at other alternatives	Process Plan
0:21.20	Wonders about seismic loads	Process Plan
0:22.00	Takes notes on what has done	Process Evaluation
0:22.55	Other alt. besides core is using perimeter columns but less dead load on them so needs more bays	Process Plan Domain Plan /St
0:23.50	Are braced bays in both directions possible?	Domain Plan /Sp
0:24.30	Can also look at rigid frames	Domain Plan /St
0:24.50	Thinks about client & architect needs	Domain Evaluation /A/Sp
0:25.35	Has sol'n in N-S & likes it - 5 Braced Bays in N-S	Domain Evaluation /St
0:26.30	Looks at E-W and how fit withN-1:	Domain Plan /Sp
0:26.45	Tries perimeter for location	Domain Plan /Sp
0:27.35	Draws another sketch for calcs even though sketch exists on pg.l	Sketch
0:28.10	Calc. of induced E-W force	Calculation
0:28.45	Estimates dead load on perimeter columns as half of core	Calculation
0:29.30	Evaluates location & loads for them has 4 braced bays on perimeter	Domain Evaluation /Sp/St
0:29.50	Is it ok architecturally?	Domain Evaluation /A/Sp
0:31.00	Determines if arch, would like sol'n but ok structurally - most efficient	Domain Evaluation /A/St
0:31.30	Looks at seismic to see if controls	Process Plan
0:32.20	Needs code - unfamiliar with EQ	Process Plan
0:33.40	Looks at formulas & filling in values - does by floor	Calculation
0:36.55	Did EQ calcs in wrong direction so redoes calcs	Calculation
0:37.55	Compares seismic to wind load	Domain Evaluation /St

Time h:mm.ss	Description	Activity
0:38.35	Needs more detail calcs. as close to wind load	Domain Evaluation /St
0:39.20	Judgment is seismic governs E-W and says 30% higher than wind	Domain Evaluation /St
0:40.30	Increases wind load by 30% in E-W	Process Plan
0:41.20	How to use new overturning moment	Process Plan
0:41.25	Applies to 4 braced bays & gets induced axial load	Calculation
0:41.50	Axial load about equal dead load so no safety factor - not good	Domain Evaluation /St
0:42.15	Thinks about solutions that will work - add more braced frames	Domain Plan/St/Sp
0:43.10	If change framing pattern so columns pick up more dead load - not justified for speculative office building	Domain Plan /St/Sp
0:43.40	Using 6 braced frames will woik	Domain Evaluation /St
0:44.00	Symmetric way to do it	Domain Evaluation /Sp
0:44.20	Could change bay size to get more load	Domain Plan /Sp
0:44.30	Use 6 if had to answer now, but doesn't like solution - thinking	Domain Evaluation /St
0:44.50	Where to locate the 6	Domain Plan /Sp
0:45.50	Can't use core with N-S chosen	Domain Evaluation /Sp
0:46.10	Doesn't like cluttering of outside of bldg with more braced bays	Domain Evaluation /Sp
0:46.40	Alternate is braced 1 way & rigid the other way	Domain Evaluation /Sp/St
0:47.00	Use 5 braced bays in N-S	Domain Decision /St
0:48.00	Explores rigid framing in E-W	Process Plan
0:49.10	Calcs horizontal shear at base	Calculation
0:49.50	Rechecks calcs as thought used 10 story building	Calculation
0:50.20	didn't use 10 - so ok	
0:51.35	Obtains total horizontal force	Calculation

Time h:mm.ss	Description	Activity
0:51.50	Looks at possible locations for rigid frames	Domain Plan /Sp Sketch
0:52.10	Has ''good idea'' of rigid frames on perimeter as girders can be deeper there	Domain Evaluation /St/Sp
0:53.20	Use 2 rigid frames but how many bays?	Domain Decision /St
0:54.05	Thinks 6 bays excessive, 2 not adequate, so use 4 bays for frames	Domain Plan /Sp
0:54.45	How to tell if 4 ok?	Domain Plan /St
0:54.55	Decides to look at girder moments	Process Plan
0:55.30	Calculates girder moment for 4 bay	Calculation
0.56.45	Gets girder moment - also is equal to worse column moment	
0:57.40	Evaluates that not using forces below grade - only first story	Domain Evaluation /St
0:58.10	Can these moments be carried?	Domain Evaluation /St
0:58.40	Compares these wind moments to gravity moments	Domain Plan /St
1:00.00	Gets gravity load moment in girder	Calculation
1:00.15	Compares G.L. moment to Wind is favorable as wind load gets 33% reduction	Domain Evaluation /St
1:01.05	Wind moment at end of girder and gravity moment at middle so minimal penalty for this girder to carry both	Domain Evaluation /St
1:01.45	Thinks about 2 bay frame - moment 2X this and that would be too much to handle	Domain Evaluation /St
1:02.30	Also can say no efficiency in 6 bay frame	Domain Evaluation /St
1:02.40	Looks at columns	Process Plan
1:03.15	Looks at D.L. on core columns	Calculation
1:03.55	D.L. on perimeter is half core	Calculation
1:04.20	Wants cross sectional areas needed Looks at tables - core 114x342, per. 114x193	Calculation
1:05.20	Gets stress of bending moment in per.	Calculation
1:06.10	Gets stress of 13ksi	Calculation

Time h:mm.ss	Description	Activity
1:06.15	Evaluates stress of axial & bending	Domain Evaluation /St
1:06.45	Thinks stress ok	Domain Evaluation /St
1:07.15	Columns won't get grossly big when adding bending to D.L.	Domain Evaluation /St
1:07.30	Prepared w/a sol'n	Domain Decision /St/Sp
1:07.45	Sketches sol'n - 2 rigid 4 bay frames on perimeter E-W -5 braced bays N-S	Sketch
1:09.00	Sol'n gives direction of floor beams E-W	Domain Plan /St
1:09.25	Thinks sol'n reasonable	Domain Evaluation /St
1:09.35	Wonders how HVAC will effect	Domain Evaluation /A
1:10.30	Looks at floor system depth req'ment	Process Plan
1:11.15	Looks at interior girder and max moment	Calculation
1:11.45	Has moment and get req'd section modulus	Calculation
1:12.05	Looks in table for girder	Calculation
1:12.55	Will be tight & weight penalties with rigid depth, but ok	Domain Evaluation /St/Sp
1:13.15	Finished with problem one	

B.1.2 Problem 2

Time h:mm.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:01.15	Starts to relate to Problem 1 Spatial differences: length 300% 2 cores, 30 stories	Domain Plan /Sp/St
0:01.45	Begins thinking - "can scale" Prob. 1	Domain Plan /Sp
0:02.20	Wind load significantly N-S higher than E-W	Domain Plan /St
0:02.35	Calculates total height	Calculation
0:02.55	Concerned bldg. high for footprint	Domain Evaluation /St
0:03.05	Thinks cores are facing wrong way	Domain Evaluation /St
0:03.25	Sees problems w/ wind load in N-S doesn't think can handle it efficiently	Domain Evaluation /St
0:03.40	Thinks about E-W direction wind load	Process Decision
0:03.55	Says 2 design choices rigid frame (doesn't say 2nd now)	Domain Plan/St
0:04.20	Compares to previous design to get horizontal force in E-W	Calculation
0:05.35	Total H 3x higher than Prob. 1	Calculation
0:05.55	Looks at rigid framing, but not sure can use with 3x higher load	Domain Evaluation /St
0:06.20	Uses core in 60' E-W as 2nd alt for 4-60' deep braced bays	Domain Plan /St
0:07.15	Could also be shear walls rather than trusses	Domain Plan /St
0:07.45	Begins calc. E-W for the E-W trusses	Calculation
0:08.10	Wants to find location of H total for moment arm	Process Plan
0:09.00	Obtains Total Overturning Moment	Calculation
0:09.15	Tries 4-60* deep braced frames	Domain Plan /Sp
0:09.35	Calculates induced load	Calculation
0:09.50	Uses bay size of 3O'x35' then calcs dead load on core	Domain Plan /Sp
0:10.15	Assumes DL is 2x Prob. 1	Domain Decision /St
0:10.35	Likes results, can do w/ steel and 4 braced bays 60' deep	Domain Evaluation /Sp/St

Time h:mm.ss	Description	Activity
0:11.10	While looking E-W study rigid framing	Process Plan
0:11.40	Realizes must go back & recalc 'C factor for seismic & not directly applicable from Prob. 1	Domain Evaluation /St
0:12.20	Worries about wrong $^9C*$ factor for Prob. 1 - ignore	Domain Evaluation /St
0:12.55	Starts 'C factor calcs for this prob.	Calculation
0:13.50	Gets 'C factor - not much different than before	Calculation
0:14.10	Recalculates Total Overturning Moment	Calculation
0:14.45	Realizes 4 braced bays still ok - even more conservative	Domain Evaluation /St
0:15.00	Recalcs 'C for rigid frame	Calculation
0:15.30	Obtains 'C	Calculation
0:15.35	Now get H total with new 'C	Calculation
0:16.25	Compares findings to Prob. 1 - says Prob. 1 sol'n still valid	Domain Evaluation /St
0:17.15	Floor area 3x higher so dead load is 3x higher	Calculation
0:17.40	Gets H total	Calculation
0:17.45	Compares H total w/ braced bay above compares K 33% reduction & 'C reduction	Domain Evaluation /St
0:18.50	so thinks H total is ok	Domain Evaluation /St
0:19.05	Shows how rigid frame more efficient for seismic load	Domain Evaluation /St
0:19.40	Calcs. total wind load in E-W to see if controls	Process Plan
0:20.05	Finds wind load controls for rigid frame	Calculation
0:20.30	Refers to Prob 1 & says need 2x as much structural capacity	Domain Evaluation /St
0:20.55	So use 4 - 4 bay rigid frames	Domain Decision /St
0:21.20	Could also use 2 - 6 or 7 bay rigid frames on perimeter	Domain Decision /Sp/St

Time h:mm.ss	Description	Activity
0:21.40	Summarizes E-W direction 4-60' trusses; or4 - 4bay rigid frames; or 2 - 6 or 7 bay rigid frames	Domain Evaluation /Sp/St
0:22.15	Now looks at N-S	Process Plan
0:22.25	Says wind load governs	Domain Evaluation /St
0:22.35	Factor up Total Overturning Moment from Prob. 1	Calculation
0:22.55	Evaluates size of OM total	Domain Evaluation /St
0:23.30	Looks at H total	Domain Evaluation /St
0:24.00	These loads very high - tall bldg.	Domain Evaluation /St
0:24.15	Idea to use 2 -100* deep trusses at ends - had been pondering size of loads	Domain Plan /Sp
0:24.45	Asks what about shear walls?	Domain Plan /St
0:24.55	Looks at trusses first	Process Plan
0:25.05	Calcs. induced axial load	Calculation
0:25.20	Gets P induced	Calculation
0:25.35	Calcs req'd DL to do this option	Calculation
0:26.05	How much floor area needed to get that much Dead Load	Domain Plan /St
0:26.50	Gets area needed 1600 sq. ft. says that is about 40'x40*	Calculation
0:27.15	Can't do that unless transfer DL into these columns	Domain Evaluation /St
0:27.45	If can transfer DL what is effect of DL + LL on columns?	Domain Plan /St
0:28.00	Gets DL + LL	Calculation
0:28.10	How big is column to carry this?	Domain Evaluation /St
0:28.20	Looks in tables	Calculation
0:28.35	Would be built-up section	Domain Decision /St
0:28.55	This alt requires really big corner columns	Domain Evaluation /St
0:29.20	Could do if build 2 of these trusses on either end of building	Domain Evaluation /St
0:29.30	Imagines architectural effects	Domain Evaluation /A
0:29.50	Would be visual - 3 or 4 level truss	Domain Evaluation /A

Time h:mm.ss	Description	Activity
0:30.10	Would recommend to client to do this in steel	Domain Decision /St
0:30.40	Several problems - built-up of corner columns	Domain Evaluation /St
0:30.55	Using trusses on perimeter	Domain Decision /Sp
0:31.45	What about conventional braced bays in N-S?	Domain Plan/St
0:31.55	Doesn't think will work	Domain Evaluation /St
0:32.15	Begins calcs - doubled values of Prob. 1 for axial dead load	Calculation
0:32.40	Gets induced load	Calculation
0:32.55	How many bays needed?	Process Plan
0:33.30	Finds needs 9 braced bays	Calculation
0:33.50	See if have 9 bays	Domain Plan /Sp
0:33.55	Maybe alt. not unreasonable suggestion	Domain Evaluation /Sp
0:34.20	Looks at sketch - have 9 30' bays	Sketch
0:34.40	6 of these bays are in core	Domain Evaluation /Sp
0:35.05	This idea ok also	Domain Evaluation /Sp
0:35.15	If use 9 interior braced bays then precludes E-W choice of 4 - 60' trusses	Domain Evaluation /Sp
0:35.45	Surprised by result of braced bays	Domain Evaluation /St
0:36.00	So use E-W rigid	Domain Decision /St
0:36.10	and sol'n to this is scale-up of Prob. 1	Domain Evaluation /St
0:36.30	Struct, suggestion to architect is to look at end trusses for effect w/ 4 - 60' rigid frames in E-W	Domain Decision /A
0:37.05	What about shear walls?	Domain Plan /St
0:37.20	Doesn't do as client would want end walls free of obstruction for view	Domain Evaluation /A
0:37.50	Is it worth checking rigid in N-S?	Domain Plan /St
0:38.15	Would be expensive & inefficient	Domain Evaluation /St
0:38.20	Done with Prob. 2 with several sol'ns. AlLl: 2 - 100' deep trusses at ends for N-S and 4 - 60' trusses in core E-W AlL 2: 9 - 30' trusses in interior N-S and 2 - 6 or 7 bay rigid frames in E-W	Domain Decision /Sp/St

B.13 Problem 3

Time h:mm.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:0125	End reading Prob.	
0:01.30	Not familiar w/ type prob.	Process Evaluation
0:01.40	Starts collecting thoughts	Process Plan
0:01.50	2 towers overlap by 100'xlOO' square	Domain Plan /Sp
0:02.10	Have common core - much too small	Domain Evaluation /St
0:02.25	Ignore core for structural purpose	Domain Evaluation /St
0:02.40	100'xlOO' would be nice struct, spine but reject for circulation reason	Domain Evaluation /Sp
0:03.10	Different req'ments for 15 vs 25 story, but not vastly different	Domain Plan /St
0:03.45	Approach as uniform sol'n & difference are in member sizes	Domain Plan /St
0:04.10	Total height 250*	Calculation
0:04.25	Not particularly high for footprint	Domain Evaluation /St
0:04.35	Looking for approach to provide struct, sol'ns broadly applicable	Process Plan
0:05.00	Looking at whether corners are appropriate to use	Domain Plan /Sp
0:05.15	Use corners w/ shear walls - disadvantageous of blocking best rental space	Domain Decision /St Domain Evaluation /A
0:05.40	"blank mind"	
0:06.00	Looking for logical geometric generator and don't see it	Domain Plan /Sp
0:06.15	30' or 40' bay spacing	Sketch
0:06.35	Means 6 bays each way	Domain Evaluation /Sp
0:06.50	"nothing that jumps out as starting point"	Domain Evaluation /Sp
0:07.05	Would like to see large core	Domain Plan /Sp
0:07.25	Core to small to use	Domain Evaluation /St
0:08.05	What would core do if closed box 40' square?	Domain Plan /St
0:08.30	Could probably handle lateral load	Domain Evaluation /St
0:08.50	but useless investigation	

Time h:mm.ss	Description	Activity
0:09.00	Looking for something geometrical	Domain Plan /Sp
0:09.10	Don't like 6 bays each direction	Domain Evaluation /Sp
0:09.25	Intersection complicates prob. as restricts flow	Domain Evaluation /A
0:09.45	Rejects comers as rental space	Domain Evaluation /A
0:09.50	Rejects core	Domain Decision /St
0:10.00	Thinking about atrium	Process Plan
0:10.15	Realizes actually 2 problems to design	Process Evaluation
0:10.30	Silence - thinking	Process Plan
0:10.55	Don't see strong reasons for structural system	Domain Plan /Sp
0:11.10	Square not obvious which way things go	Domain Evaluation /Sp
0:11.30	Neither bldg is extraordinary loaded laterally	Domain Evaluation /St
0:11.55	Probably seek reasonable grid & fit some structural sol'ns to it	Domain Plan /Sp/St
0:12.15	Difficult w/o graph paper	Sketch
0:12.30	Sketching	Sketch
0:12.45	Grid established where have 100' dimension	Domain Evaluation /Sp
0:13.00	Wants sketch to scale to better visualize	Sketch
0:13.25	Grid set up 30', 40', 30'	Domain Decision /Sp
0:13.35	Same in other direction & tower	Domain Decision /Sp
0:14.05	Sees no reason to maintain grid or to change it	Domain Evaluation /Sp
0:14.25	Will repeat the grid in other tower	Domain Plan /Sp
0:14.40	Have busy column grid	Domain Evaluation /Sp
0:14.50	Let's make some general statements	Domain Plan /St
0:15.00	What req'd to carry 15 story square?	Domain Plan /St
0:15.20	Relates to Prob. 1	Calculation
0:15.35	Needed 5 interior braced bays before	Domain Evaluation /St
0:15.50	Needs 5 interior braced bays for 15 story	Domain Decision /St
0:16.00	or need 10 perimeter braced bays	Domain Decision /Sp
0:16.20	What if rigid framing?	Domain Plan /St

Time h:mm.ss	Description	Activity
0:16.30	Prob. 1 had 2 - 4 bay rigid frames	Calculation
0:17.00	Needs 2 - 5 bay now	Domain Decision /St
0:17.15	or 4 - 3 bay rigid frames	Domain Decision /St
0:17.30	Looks at 25 story tower	Process Plan
0:18.05	Prob. 1 had 9 braced bays	Calculation
0:18.15	but was 300' wide	Calculation
0:18.30	Looking at paper of Prob. 1 & 2	Calculation
0:19.15	Troubled by answer previously as might be inconsistent	Domain Evaluation /St
0:19.50	Realizes made mistake of OM total in N-S didn't do w/ 300' face, only used 200' face	Domain Decision /St
0:20.15	so 9 braced bays not acceptable for Prob. 2 as his judgment was	Domain Evaluation /St
0:20.35	so 9 braced ok for 200	Calculation
0:20.50	so need 7 braced now	Domain Decision /St
0:21.10	Guesses 3 - 5 bay rigid bay needed or 4 - 4 bay rigid frames	Domain Decision /St
0:21.25	Not rigid constraints in these as can change girder sizes	Domain Evaluation /St
0:21.50	Use these for "planning purposes"	Domain Plan /St
0:22.10	Have a lot of interior bays - 19	Domain Evaluation /Sp
0:22.35	4 bays overlap	Domain Evaluation /Sp
0:22.45	Should not be difficult to find 5 in 15 story and 7 in 25 story	Process Plan
0:23.05	So should be able to do in 1 direction	Process Plan
0:23.10	Now if use in other direction	Process Plan
0:23.25	Now let me fiddle w/ some ideas (sketching)	Domain Plan /Sp
0:23.55	No logical place to put them	Domain Evaluation /Sp
0:24.40	Can place 4 E-W but not symmetric	Domain Evaluation /Sp
0:25.00	If want to build 15 story w/ braced bays then can fit 5 in each direction w/o excessively constraining space	Domain Plan/St/Sp
0:25.30	This was first alt.	Domain Decision /St
0:25.50	Braced in 1 direction & rigid in other allows space to open	Domain Plan /Sp

Time h:mm.ss	Description	Activity
0:26.10	Other reason to use rigid as girders carry gravity load anyway so pick up for free + framing cost	Domain Evaluation /St
0:26.45	Probably recommend: 5 braced bays in 1 direction & 4 - 3 bay rigid frame in other	Domain Decision /St/Sp
0:27.35	Draws sketch - still not symmetric	Sketch
0:28.00	Preferred sol'n is what can go on perimeter and begins to like	Domain Evaluation /Sp
0:28.20	Have 2 - 6 bay frames on perimeter which should work	Domain Plan /Sp
0:28.40	but not in same direction	Domain Evaluation /Sp
0:28.50	but interesting idea - beginning to "structural sense"	Domain Evaluation /St
0:29.15	Can do 1 - 6 bay frame each direction on perimeter	Domain Plan /Sp
0:29.45	but is wasting efficient braced frame inside	Domain Evaluation /St
0:30.00	Maybe 6 bay frame on each exterior long wail	Domain Plan /Sp
0:30.20	Should work or both towers	Domain Evaluation /Sp/St
0:30.45	Likes this idea a lot	
0:30.50	This idea has "creative juice" to it	Domain Evaluation /Sp/St
0:31.05	Rec. to client could do w/ reinf. cone. on perimeter for rigid frame	Domain Decision /St
0:31.25	This gives visual reality	Domain Evaluation /A
0:31.45	Arch, may like exposed cone. both size and color	Domain Evaluation /A
0:32.30	Could also do in single tower as number rigid bays needed is different	Domain Evaluation /Sp
0:33.00	So could do sketch - less cone. as height goes up - staggered	Domain Plan /Sp
0:33.40	Other part could be steel	Domain Plan /St
0:33.55	Give interesting result	Domain Evaluation /A

Time hrmm.ss	Description	Activity
0:34.15	Likes idea of this appearance	Domain Evaluation /A
0:34.50	Arch, interested in having long walls in cone. & others in steel as gives different surface textures	Domain Evaluation /A
0:35.20	Likes this idea	Process Evaluation
0:35.40	Would reject structure inside for carrying lateral load	Domain Decision /St
0:35.55	Rejecting use of girders which carry gravity load for also lateral load	Domain Decision /St
0:36.20	So several inefficiencies	Domain Evaluation /St
0:36.45	"have to let something generate the design"	Process Evaluation
0:37.05	So above would be my suggestion	Domain Decision /St
0:37.15	Starts on part b of prob.	Process Decision
0:37.25	In general might be good for atrium to have separate framing	Domain Plan /St
0:37.50	New sketch - trouble drawing it	Sketch
0:38.40	100'xlOO* probably should have own framing for gravity loads	Domain Plan /St
0:39.15	Must have some system of roof trusses	Domain Plan /St
0:39.30	Support roof trusses with ...	Domain Plan/St
0:40.00	Would like atrium shown differently visually from rest of bldg.	Domain Evaluation /A
0:40.25	Trusses very big as pick up loads above	Domain Evaluation /St
0:41.05	The atrium is accommodated in this bldg as lat. system on outside	Domain Decision /St
0:41.30	Atrium spatially independent	Domain Evaluation /Sp
0:41.45	Should atrium be closely coupled?	Domain Plan/St
0:42.20	Doesn't pursue as not necessary	Domain Decision /St
0:43.20	Could put in a lot of time on more meaningful analysis and not much difference in results	Domain Evaluation /St
0:43.45	Done with Prob. 3	

B.1.4 Discussion Answers

Expert 1 - Discussion Transcript

1. *How important is scale?* **For moderate height buildings the lateral load doubles as the width doubles. The number of grid points increases as the square of the footprint dimensions, so there are many more locations to fit the structural system. It loosens the fit between structural geometry and building geometry. Extremes give problems as there are many locations to place few lateral systems in a short building.**
2. *At what stage do you normally interact with the architect?* **I am not contacted by the client, but by the architect. The architect has some degree of ideas, but they are not fixed. It is fairly easy to modify things rather than move them.**
3. *How do the designs for commercial space differ from office space?* **The influence can go both ways. An office can be arranged in many ways so the space could be closed, but one wants a lot of combinations so the space should be open. Retail space should be open.**
4. *At what stage do you select material for structural framing?* **Material selection is made very early in the process and is based on availability, speed of construction, and local contractor strengths. Building scale and visibility may also influence material selection.**
5. *How does complexity of building geometry affect the design process?* **Geometry affects it significantly. Geometry is the most important aspect of a building's systems - as it gets more complex so does everything else.**
6. *Do you idealize complex geometries of buildings into simpler ones?* **In reference to problem 31 do not idealize. I try to key on salient geometric features to key the solutions.**
7. *What problems seem to most often cause difficulty with design?* **The more choices of placement, the harder it is to place systems - this inhibits the advancement of design. Other problems are conflicting demands for the same solution and certain geometries will not have desirable alternatives.**

B.2 Expert 2

B2.1 Problem 1

Time h:mm.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:01.00	Summarizes Problem - 15 story 150' tall	Process Evaluation
0:01.25	has core which may or may not be used	Domain Evaluation /St
0:01.35	Not a large wind load	Domain Evaluation /St
0:01.50	Want flexibility of office arrangement	Domain Plan /A
0:02.00	First thing, this is not a tall bldg	Domain Plan /St
0:02.20	Aspect ratio low - is 1.5	Domain Plan /St
0:02.40	Most flexible bldg is to go with moment-resisting frame	Domain Plan /St
0:02.55	Tries to layout column locations	Domain Plan /Sp
0:03.10	30'x 30'bay; most economical	Domain Plan /Sp
0:03.30	Place columns in long direction Sketching column location	Domain Plan /Sp
0:04.10	Gives very strong frame - 6 bay no problem resisting wind load	Domain Evaluation /Sp/St
0:04.25	Place columns in short direction	Domain Plan /Sp
0:04.35	Gives strong 3 bay frame	Domain Evaluation /Sp/St
0:04.55	have 7 locations to place them	Domain Evaluation /Sp
0:05.05	Draws sketch on pad of column location	Sketch
0:05.25	Reviews spatial locations of frames	Domain Evaluation /Sp
0:06.00	Use exterior for lateral frames to minimize impact	Domain Decision /Sp
0:06.20	Span floor beam N-S due to strongest direction	Domain Decision /Sp/St
0:06.40	Only gravity loads for floor beams	Domain Plan /St
0:07.00	Draws core	Sketch
0:07.10	Maybe 6 frames N-S rather than 7 due to core location	Domain Evaluation /Sp

Time h:mm.ss	Description	Activity
0:07.25	What part of country is bldg located?	Input
0:07.35	Concrete vs. Steel cost is by location	Domain Evaluation /St
0:07.50	If in Atlanta - definitely use concrete	Domain Decision /St
0:08.10	Beams on column lines for lateral load	Domain Decision /Sp
0:08.20	10* c-c skip joist between	Domain Decision /St
0:08.50	Min. slab req'ments for fire rating	Domain Decision /St
0:09.10	Without calc. have 18.5" depth of structure 4.5" slab, 14" pan system, rest ceiling	Domain Decision /St
0:09.45	Need to identify column size	Process Plan
0:10.00	Max. area is 35'x 30* Calculate square footage	Calculation
0:10.15	Gravity live load is 100 psf	Input
0:10.30	Use 60% due to LL reduction	Domain Decision /St
0:10.45	Dead load - 80 psf	Domain Decision /St
0:10.55	add 15 psf misc. load	Domain Decision /St
0:11.00	Calcs. total load	Calculation
0:11.15	Total load on bottom column	Calculation
0:11.45	Gets ultimate load 2550k	Calculation
0:12.00	Deciding size from expertise	Domain Decision /St
0:12.20	Use 30" square col. 5000psiconc.	Domain Decision /St
0:12.40	Better use 6000 psi cone.	Domain Evaluation /St
0:12.50	Girder size of 42" wide x 18.5"	Domain Decision /St
0:13.15	Floor beam size of 12" x 18"	Domain Decision /St
0:13.30	Have sized main beams, floor beams, column and slabs	Process Evaluation
0:13.45	Still have to do foundation	Process Plan
0:14.05	Use caisson since rock present	Domain Decision /St
0:14.15	Calcs. size of caisson	Calculation
0:14.30	Try 36" caisson	Process Plan
0:14.40	Use 5000 psi cone.	Domain Decision /St
0:14.45	Not enough - so go to 42" caisson	Domain Evaluation /St
0:14.50	Starts calculation	Calculation
0:15.20	Getting P for caisson	Calculation
0:15.45	42" ok 5000 psi	Domain Decision /St
0:16.00	Can caisson be straight shaft or bell	Process Plan
0:16.05	Calcs. bearing stress	Calculation
0:17.00	Need bell shaft	Domain Decision /St

Time hrmm.ss	Description	Activity
0:17.15	Evaluates what has done	Process Evaluation
0:17.30	Short height - low aspect ratio	Domain Evaluation /St
0:17.45	Look @ wind effect when run analysis	Domain Evaluation /St
0:18.00	Now if steel is used	Process Decision
0:18.20	Layout will be same	Domain Plan /Sp
0:18.35	Relate to previous decisions	Domain Plan /St
0:18.45	Substitute filler beam for cone, joist	Domain Decision /St
0:19.05	For 30' - 35* span, beam sizes in range of 36 - 40 lbTlin. ft	Domain Decision /St
0:19.40	socouldbeW16's	Domain Decision /St
0:19.45	Decides to look in AISC	Calculation
0:20.10	W16 depth better for deflection	Domain Evaluation /St
0:20.30	W16x36 or W12x40 with shoring	Domain Decision /St
0:21.10	That takes care of filler beams	Process Evaluation
0:21.30	Look at main beams - range 27-30 depth	Process Plan
0:21.40	Looks in AISC	Calculation
0:21.50	W27x84 to W30x90	Domain Decision /St
0:22.10	Look at column sizes	Process Plan
0:22.15	SizeisaW14	Domain Decision /St
0:22.25	Looks in AISC for weight	Calculation
0:23.00	W14x605 size chosen for max. column	Domain Decision /St
0:23.25	Reduce col. size through height of bldg.	Domain Decision /St
0:23.45	slab thickness size is: 3" metal deck, 3.25" semi-lightweight cone. - 120pcf	Domain Decision /St
0:24.20	Calcs. total wt. of bldg.	Calculation
0:25.35	50 lb. cone; 60 lb. reduced LL; 15 lb. misc.	Domain Decision /St
0:24.55	125 psf total loading	Calculation
0:25.00	Calculates P working	Calculation
0:25.15	Scales from before to get P	Calculation
0:25.25	Has number for P working	Calculation
0:25.40	So could reduce column size	Domain Evaluation /St
0:25.45	Looks in AISC tables	Calculation
0:26.05	Picks new size W14x426	Domain Decision /St
0:26.30	Look at caisson	Process Plan
0:26.45	Decides to reduce caisson to 36" dia.	Domain Decision /St
0:26.55	Evaluates this bldg. - smaller caisson	Domain Evaluation /St

Time h:mm.ss	Description	Activity
0:27.10	This design has identified major elements, so now arch, can layout floor	Process Evaluation
	Questions about Problem 1	
0:27.30	He is questioned if 10' floor to floor works using his sizes	
0:28.10	must have 3.5' - 4' for HVAC, struct system - so wants min 12' floor to floor	
0:28.40	If force 10' min., can't do practically	
0:29.30	Tell arch. 10' floor to floor must be changed	
0:30.00	If had lower ceiling req'ment might be able to do - still inefficient	
0:30.45	With 7' ceiling still not enough struct, depth for 35' span	
0:31.00	With 7' ceiling could force 14" cone, depth	
0:32.00	He is questioned if any other recommendations	
0:32.10	Looking at spatial 30' bay is great	
0:32.25	Can't see anything that makes bldg. more effective	
0:32.50	Bldg. looks very typical	
0:33.00	100' x 200' typical outer envelope	
0:33.20	Spans could be played w/ a little but sizes still about the same	
0:34.10	Could go to longer base dimension but get greater depth & cost increases say span of 70'	
0:34.50	Then struct, for gravity gives you big problems - expensive, but could do if had to	
0:35.15	Reread prob. to see if did it all	
0:35.35	From my experience seem a lot of similar bldgs. for speculative office bldgs. with similar column arrangements	
0:36.00	This is as good of sol'n as can get	
0:36.25	End of Problem 1	

B22 **Problem 2**

Time **himm.ss**	**Description**	**Activity**
0:00.00	**Reads Problem Statement**	**Input**
0:01.15	**Look at building first**	**Process Plan**
0:01.20	**Bldg has 2 cores 120' apart external bay of 30'**	**Process Evaluation**
0:01.50	**10' floor to floor unrealistic**	**Domain Decision /St**
0:02.00	**From previous experience did a bldg with 11.5' floor to floor - this bldg would not work today**	**Domain Evaluation /St**
0:02.30	**Need at least 12* floor to floor**	**Domain Decision /St**
0:02.50	**Point out to arch, need more floor to floor height**	**Domain Plan /St**
0:03.10	**Struct, depth at least 3'**	**Domain Decision /St**
0:03.30	**For this height bldg., steel could be as economical as concrete**	**Domain Evaluation /St**
0:03.45	**First look at struct steel**	**Process Decision**
0:04.00	**Need 3'-6" struct depth using concrete floor: 3' struct., 6" floor 8.5' floor to ceiling**	**Domain Plan/St**
0:04.55	**Total floor to floor is 12'**	**Domain Plan /St**
0:05.10	**Clarify with arch, the 12'**	**Domain Plan/St**
0:05.20	**Assume can use 12'**	**Domain Decision /St**
0:05.50	**Gets total height of bldg**	**Calculation**
0:06.05	**Desirable to achieve frame & shear wall for economics**	**Domain Plan /St**
0:06.30	**Most critical dimension is narrow side -100***	**Domain Evaluation /St**
0:06.55	**Concentrate on...**	**Process Plan**
0:07.05	**Sketches bldg to "see better" Draws to Scale**	**Sketch**
0:08.30	**Look at locations for X-bracing**	**Domain Plan /Sp**
0:08.40	**Draws symmetrical**	**Sketch**
0:09.00	**Place columns**	**Domain Plan /Sp**
0:09.30	**Now Use X-bracing & moment frame**	**Process Decision**
0:09.40	**Place 4 frames in each half & 1 at middle**	**Domain Decision /Sp**

Time h:mm.ss	Description	Activity
0:10.00	Total of 9 frames & X-bracing	Domain Decision /Sp
0:10.15	Calcs. aspect ratio of bldg.	Calculation
0:10.25	Good aspect value - comfortable	Domain Evaluation /St
0:10.40	Find out if can have X-bracing does it interfere with arch, doors?	Domain Plan /A
0:11.00	Assume ok, & go ahead and design	Domain Decision /A
0:11.05	Have main frame beam on column line	Domain Plan /Sp
0:11.25	Use only frame in long direction as lots of length in bldg.	Domain Decision /St
0:11.45	For steel I would run filler beams in...	Domain Plan /Sp
0:12.20	Long direction (N-S) using composite design	Domain Decision /Sp
0:12.45	HVAC right under it for penetration of main beams	Domain Decision /St
0:12.55	Sketches filler beams	Sketch
0:13.15	Need sizes of beams	Process Plan
0:13.30	Would run 2D computer analysis	Process Plan
0:13.45	Link up frames	Domain Plan/St
0:13.55	To get initial member sizes use gravity only	Domain Decision /St
0:14.10	Then see how close analysis comes	Process Evaluation
0:14.30	Now do same as did before (To determine prelim, sizes)	Process Plan
0:14.45	Filler beams first	Process Decision
0:14.50	Get load of deck & live	Process Plan
0:14.55	Starts calculations	Calculation
0:15.40	Gets total load -165 psf	Calculation
0:15.50	Looks in AISC for design of composite table - doesn't find	Process Decision
0:16.10	From past experience floor beams in range of 36-40 lbs.	Domain Evaluation /St
0:16.40	UseW16X?	Domain Plan /St
0:16.50	Looks in AISC	Calculation
0:17.10	Use W16x40 composite	Domain Decision /St
0:17.35	Typical beam size would be...	Process Plan
0:17.55	Finds reaction	Calculation
0:19.50	Finds total load on beam	Calculation
0:20.05	Wt.ofbeam~1001b/ft	Calculation

Time h:mm.ss	Description	Activity
0:20.15	Find moment	Process Plan
0:20.25	Finds reaction due to 2 pt. load in AISC	Calculation
0:20.55	Finds formula	Domain Decision /St
0:21.20	Not right formula	Domain Evaluation /St
0:21.30	Finds right one	Domain Decision /St
0:22.00	Substitutes values into eq'n	Calculation
0:22.15	Calcs. moment	Calculation
0:22.30	Answer not right	Domain Evaluation /St
0:22.35	What is uniform moment?	Process Plan
0:22.45	What is w?	Process Plan
0:23.00	Gets w	Calculation
0:2320	Gets moment due to uniform	Calculation
0:23.30	So previous 2 pt. moment was a mistake	Domain Evaluation /St
0:23.45	Looks in AISC for beam	Calculation
0:24.15	Picks typical frame beams as W27x84	Domain Decision /St
0:24.40	Look at depth for penetration of HVAC	Domain Plan /St
0:25.00	Make beam 30" so can get penetration	Domain Decision /St
0:25.10	Looks in AISC	Calculation
0:25.20	Use W30x99	Domain Decision /St
0:25.55	Gives 4" from bottom of flange	Domain Evaluation /St
0:26.00	Explains depth calc. of penetration	Domain Evaluation /St
0:26.15	Draws sketch	Sketch
0:26.35	Keep secondary beam shallow	Domain Decision /St
0:27.00	Duct is 10"-11 "deep	Domain Decision /St
0:27.10	If 16" deep secondary beam then no much left in main beam for penetration	Domain Evaluation /St
0:27.55	Normally keep 3"-4" distance from bottom of flange to penetration so can reinforce	Domain Decision /St
0:28.25	So 27" too shallow unless can use 14" filler beam	Domain Evaluation /St
0:29.00	Stick with 30" deep beam	Domain Decision /St
0:29.10	Major columns are...	Process Plan
0:29.20	Calcs. Reduced LL on column	Calculation
0:29.30	Calcs. DL + Misc on column	Calculation

Time h:mm.ss	Description	Activity
0:29.45	Calcs. total load on col. at base	Calculation
0:30.00	Probably need jumbo column	Domain Decision /St
0:30.10	Looks in AISC	Calculation
0:30.15	Start w/W14x730	Domain Decision /St
0:30.25	Reduce size as go up every other floor by one size	Domain Decision /St
0:31.00	Run frame action	Process Plan
0:31.10	This establishes basic sizes for 2D computer analysis	Process Evaluation
0:31.25	Establish sizes w/ arch, layout for bracing	Process Plan
0:31.45	Look at penetration for arch. frame bracing	Process Plan
0:32.00	Difficult to do decent analysis by hand in short time	Process Evaluation
0:32.30	Can do this for 1st sizes in computer run	Process Evaluation
0:33.00	Does bldg. have validity for cone?	Process Plan
0:33.20	In southern US have good chance	Process Decision
0:33.30	Relates io previous job in cone.	Process Evaluation
0:34.00	Did one before & was cheaper	Process Evaluation
0:34.20	Use same kind of system	Domain Decision /St
0:34.30	Use shear walls for bracing	Domain Decision /St
0:34.40	12" wall from experience	Domain Decision /St
0:34.50	Frame beams very similar - 42^{tf}xl8.5^{lf} deep	Domain Decision /St
0:35.05	Advantage of concrete - gives more flexibility for HVAC	Domain Evaluation /St
0:35.20	Cone, gives more flexibility to tenant & HVAC needs	Domain Evaluation /St
0:35.50	So is cost effective to use concrete for 30 story building	Process Evaluation
0:36.10	Need to size caisson	Process Plan
0:36.15	Cheapest if strata is 20* below surface	Domain Evaluation /St
0:36.30	Caisson foundation is system to use	Domain Decision /St
0:36.45	Try 48" dia. caisson	Domain Plan /St
0:37.00	Calcs. load on caisson	Calculation
0:37.15	Using 5000 psi concrete	Domain Decision /St
0:37.20	Calcs. forces	Calculation

Time hrmm.ss	Description	Activity
0:37.45	Not big enough	Domain Evaluation /St
0:37.50	Is only 2713k compression force & less than 3750k needed	Domain Evaluation /St
0:38.05	Try 60" dia. caisson	Domain Plan /St
0:38.15	Calcs. load	Calculation
0:38.30	This size is ok	Domain Evaluation /St
0:38.35	Use 60" round caisson	Domain Decision /St
0:38.45	Straight shaft capacity for bearing is...	Domain Plan /St
0:38.50	Calcs. bearing stress	Calculation
0:39.25	Need 191 ksf - usually 125 ksf is maximum allowed capacity	Domain Plan/St
0:39.40	So require bell on shaft	Domain Evaluation /St
0:39.50	So have 60" caisson with bell	Domain Decision /St
0:40.00	What am I missing?	Process Plan
0:40.05	I did steel	Process Evaluation
0:40.10	If use steel, cone, causes more load so caisson changes	Domain Evaluation /St
0:40.40	So if using cone, struct is as feasible	Domain Evaluation /St
0:40.55	Column size of bldg is deterring factor for architect	Domain Evaluation /A
0:41.10	Determines column load for concrete	Calculation
0:41.40	Gets column compression force	Calculation
0:41.45	Use 6000 psi concrete	Domain Decision /St
0:42.00	Looks in CRSI handbook for column	Calculation
0:42.35	Look at 36" round first	Domain Plan /St
0:42.45	Just makes it	Domain Evaluation /St
0:42.55	Look at 40"	Domain Plan /St
0:43.10	40" is no problem	Domain Evaluation /St
0:43.25	Use 40"x40" square 6000 psi concrete for column	Domain Decision /St
0:43.40	Use 4000 psi cone, for floor	Domain Decision /St
0:43.50	Look at compression of floor due to col.	Domain Plan /St
0:44.30	Calcs. transfer load	Calculation
0:44.45	Use 5600 psi design for column as 1.4 x floor cone, is allowable	Domain Decision /St
0:45.10	Close enough	Domain Evaluation /St
0:45.15	Look at caissons	Process Plan
0:45.20	Tries 66" dia.	Calculation

Time h:mm.ss	Description	Activity
0:45.45	This size is ok	Domain Evaluation /St
0:45.50	Not bad sol'n; Column up to 40" in cone, was 36" in steel; caisson up 1 size	Domain Evaluation /St
0:46.15	Definitely consider concrete	Process Decision
0:46.30	Other sizes for concrete...	Process Plan
0:46.40	For floor framing use 42"xl8.5"	Domain Decision /St
0:46.50	Joist is 12^{M}xl8.5^{ft}	Domain Decision /St
0:47.10	Shear wall in short direction is 12" w/5600 psi cone.	Domain Decision/St
0:47.35	"That should do it"	Process Evaluation
0:47.45	Floor to floor has to be increased	Domain Evaluation /St
0:47.55	In short direction use frame & bracing	Domain Decision /St
0:48.00	In long direction, frame is enough	Domain Decision /St
0:48.10	In southern US, concrete is best	Domain Decision /St
0:48.15	In north, steel probably better	Domain Decision /St
0:48.45	"What else can I add?"	Process Plan
0:49.00	300* bldg. is pushing length - my want to consider expansion joint	Domain Evaluation /St
0:49.20	New trend is not to use exp. jt.	Domain Evaluation /St
0:49.30	Have looked at 400; bldg. w/ expansion	Domain Evaluation /St
0:49.50	By control of pouring sequence can handle additional force	Domain Evaluation /St
0:50.00	So far it has worked, no problems	Domain Evaluation /St
0:50.55	So no expansion needed for this bldg.	Domain Decision /St
0:51.15	End of Problem 2	

***B23* Problem 3**

Time h:mm.ss	Description	Activity
0:00.00	This is a more interesting problem	Process Evaluation
0:00.15	Reads Problem Statement	Input
0:01.55	Ends reading	Process Evaluation
0:02.00	Interesting because...	Process Evaluation
0:02.15	Floor layout symmetrical	Domain Evaluation /Sp
0:02.30	Interesting is where towers connect	Domain Evaluation /Sp
0:03.00	Realizes 2 problems	Process Evaluation
0:03.15	No way 10' floor to floor	Domain Decision /St
0:03.40	Same argument as before	Domain Evaluation /St
0:03.50	Minimum of 12' needed	Domain Plan /St
0:04.25	Use 12' floor to floor	Domain Decision /St
0:04.35	First consideration, how to structure bldg.	Process Plan
0:04.55	Material either way: steel or concrete	Domain Plan /St
0:05.10	Because 25 story range is economy of cone, and also steel depending on bldg's location	Domain Evaluation /St
0:05.40	Would be concrete in Atlanta	Domain Decision /St
0:06.15	Maybe steel in San Francisco due to seismic conditions	Domain Decision /St
0:06.40	25 story at leading edge of using nothing but resisting frame - building is not that high	Domain Plan /St
0:07.05	If can get good layout...	Domain Plan/St
0:07.10	Having 200' gives lots of length	Domain Evaluation /St
0:07.30	Max. height of bldg. 25x12 = 300'	Calculation
0:07.40	Aspect ratio is very low 300/200	Domain Evaluation /St
0:07.55	If use combination of lengths of both towers, the aspect ratio even lower	Domain Evaluation /St
0:08.05	Great if can get good layout	Domain Evaluation /Sp
0:08.20	Draws sketch to scale	Sketch
0:09.40	If want right number of bays, could go to 25' spacing of columns	Domain Plan /Sp
0:09.55	Would like bays closer to 30'	Domain Evaluation /Sp
0:10.05	If use 30\ have 30', 30', 40'	Domain Plan /Sp
0:10.10	That spacing is not good	Domain Evaluation /Sp

Time h:mm.ss	Description	Activity
0:10.20	Use 33.33' spacing of columns	Domain Decision /Sp
0:10.30	Draws spacing on sketch	Sketch
0:11.05	Hard to draw 33.33* spacing on small papa:	Domain Evaluation /Sp
0:11.20	Columns both directions at same spacing in both towers	Domain Decision /Sp
0:11.40	Have plenty of frame action for lateral forces	Domain Evaluation /St
0:11.55	Now is matter of sizing up structure	Process Evaluation
0:12.10	Bldg. looks so stiff	Domain Evaluation /St
0:12.20	Doesn't think lateral controls, bldg is plenty massive, plenty frame action	Domain Plan /St
0:12.45	Lateral force doesn't control	Domain Decision /St
0:12.55	Use33'-4^{M}x33'-4^{M}bay	Domain Decision /Sp
0:13.10	Design members for bay size & span	Domain Plan /St
0:13.25	If go structural steel...	Process Plan
0:13.40	Can use a lot of information from previous designs as spans in same range	Process Decision
0:14.00	Can comfortably say filler beam in 36-40 lb. range	Domain Decision /St
0:14.20	Main beams in range of 84-99 lb.	Domain Decision /St
0:14.40	Main beams 27^{tf}-30" depth	Domain Decision /St
0:14.45	Depends on HVAC as to depth of main beams	Domain Evaluation /St
0:15.05	Try 27" as lighter & more economy	Domain Plan /St
0:15.20	Try filler beam small	Domain Plan /St
0:15.30	Try W12x36 composite for filler with shoring at center during construction	Domain Plan /St
0:16.00	If can get filler to work, than a	Domain Plan /St
	27" WF will work & plenty room for HVAC penetration	Domain Evaluation /St
0:16.30	Challenge to get W12x36 to work	Domain Evaluation /St
0:16.40	6" slab+ 3/4"+ 12" beam	Calculation
0:17.00	Total depth of 18.5"	Calculation
0:17.15	Checks *Vr* (1/21.7)	Calculation
0:17.35	Ok, even for deflection	Domain Evaluation /St
0:17.45	Looks in AISC	Calculation
0:18.05	Actually W12x35 or W12x40	Domain Decision /St

Time h:mm.ss	Description	Activity
0:1825	Based on that, fillers are W12x35 or 40	Domain Decision /St
0:18.40	Main Beams W27x84	Domain Decision /St
0:18.55	Rough out uniform load	Domain Plan /St
0:19.00	Calculates w	Calculation
0:19.30	Getsw	Calculation
0:19.35	Calculates moment $wl^2/12$	Calculation
0:19.55	Gets moment - on conservative side	Domain Evaluation /St
0:20.20	Looks at table of curves in AISC	Calculation
0:20.45	Not ok, for W27.84 w/ given moment	Domain Decision /St
0:21.00	If recalculate moment better...	Domain Evaluation /St
0:21.15	Looks in AISC for moment formula for 1/3 pt. loading	Process Decision
0:21.45	Finds formula - substitute numbers	Calculation
0:22.10	Must find P load at each 1/3 pt.	Process Plan
0:22.15	Calculating P	Calculation
0:23.10	Gets P load	Process Plan
0:23.15	Calculates moment from formula	Calculation
0:25.45	Gets moment	Calculation
0:25.50	Still needs W27x90 girder	Domain Evaluation /St
0:26.10	Looks in AISC	Calculation
0:26.20	Use W27x94 for main beam	Domain Decision /St
0:26.40	Have filler beam, main beam	Process Evaluation
0:26.45	Now do columns	Process Plan
0:26.50	Calcs. load on column at base of tallest tower	Calculation
0:27.50	Gets column load	Calculation
0:27.55	Size is probably W14x?	Domain Plan/St
0:28.00	Looks ir. AISC	Calculation
0:28.15	Largest one, W 14x655 since gravity controls	Domain Decision /St
0:28.40	Looking at foundation caisson	Process Plan
0:28.50	Look at previous problems	Process Decision
0:29.00	Probably 42" caisson	Domain Plan/St
0:29.05	Checks size	Calculation
0:30.05	Won't work, look at 5' caisson	Domain Evaluation /St
0:30.20	Use 5' caisson	Domain Decision /St
0:30.30	Shaft for tallest part...	Domain Plan /St
0:30.40	Can proportion for lower tower	Domain Decision /St

Time h:mm.ss	Description	Activity
0:30.55	3'-6" caisson for lower tower	Domain Decision /St
0:31.10	Column also changes for 15 story	Domain Evaluation /St
0:31.20	Looks in AISC	Calculation
0:31.35	W14x398 for lower tower	Domain Decision /St
0:32.00	See if low-rise works for 42M caisson	Domain Plan /St
0:32.25	Use 3'9" caisson in lower tower	Domain Decision /St
0:32.35	If use 5' caisson how is bearing?	Domain Plan /St
0:32.40	Calculates bearing	Calculation
0:33.00	Straight shaft doesn't work	Domain Evaluation /St
0:33.10	Use bell as required	Domain Decision /St
0:33.30	Takes care of structural steel	Process Evaluation
0:33.40	Now look at concrete	Process Decision
0:34.00	Concrete structure needs-	Process Plan
0:34.15	Structural depth should be 20.5" system	Domain Decision /St
0:34.35	16" pan+ 4.5" slab for a 20.5" system	Domain Evaluation /St
0:35.00	Try size of beam 42"x20.5"	Domain Plan /St
0:35.15	Get load on beam	Process Plan
0:35.20	Calculates load	Calculation
0:35.40	Have 195 psf@ 33.33*	Calculation
0:36.05	This load is 6.5 k/ft	Calculation
0:36.10	Gets moment $wl^2/12$	Calculation
0:36.15	Calculates ultimate moment	Calculation
0:36.45	Gets ultimate moment of 903 ft-k	Calculation
0:37.10	See if 42" will work	Domain Plan /St
0:37.15	Uses in house design tables	Calculation
0:37.50	Gets d for moment arm to steel	Calculation
0:38.30	Finds p from chart of 0.0175	Calculation
0:38.45	p is less than p_{max} so ok	Domain Evaluation /St
0:38.55	size ok for 42Mx20.5fl beam	Domain Decision /St
0:39.10	Joist spacing at 11.11'	Domain Plan /Sp
0:39.25	Size of joist is 12Mx20.5"	Domain Decision /St
0:39.35	Look at column size	Process Plan
0:39.40	Calcs. lead on bottom column	Calculation
0:40.40	Use 4000 psi concrete	Domain Decision /St
0:40.55	Looks in CRSI handbook	Calculation
0:41.10	5600 psi is max. concrete can use	Domain Decision /St
0:41.25	36" column would work	Domain Decision /St

Time h:mm.ss	Description	Activity
0:41.35	No, that is wrong	Domain Evaluation /St
0:41.45	Need P^ -1.5 times load	Domain Plan /St
0:42.00	Looks in CRSI	Calculation
0:42.10	Need 42^{M}x42^{tt} column @ 6000 psi	Domain Decision /St
0:42.30	Lower tower column is...	Process Plan
0:42.40	Has load on lower column	Calculation
0:42.45	Looks in CRSI	Calculation
0:42.55	So 34^{M}x34" will work for lower tower	Domain Decision /St
0:43.25	Basically that's it	Process Evaluation
0:43.30	Caisson size bigger for concrete	Domain Decision /St
0:43.55	Try 5'6" caisson	Domain Plan /St
0:44.00	Calcs. to see if works	Calculation
0:45.05	Caisson 5* (same size as steel) is ok	Domain Decision /St
0:45.25	3'-9" caisson for low rise from before	Domain Decision /St
0:45.45	Column not that different w/ load between concrete and steel	Domain Evaluation /St
0:46.15	Oh, didn't add column self-weight	Domain Evaluation /St
0:46.25	Calculates column weight	Calculation
0:46.50	Gets load with weight	Calculation
0:47.00	Check caisson size	Calculation
0:47.25	Still ok, roughly the same	Domain Evaluation /St
0:47.40	This gives rough sizes to part a) of problem	Process Evaluation
0:47.50	Now for part b) of problem	Process Decision
0:47.55	Looks at problem statement	Input
0:48.05	Size of atrium is 100'xlOO'	Input
0:48.15	Sketches atrium location	Sketch
0:48.35	Atrium middle of lower tower	Domain Plan /Sp
0:48.40	Continues sketching location	Sketch
0:49.40	Done sketching	Sketch
0:49.45	Take up 50* each side lower tower	Domain Plan /Sp
0:50.15	Now to structure building	Process Plan
0:50.25	Interesting problem - can't use other column spacing as 33.33* doesn't work	Domain Plan /Sp
0:50.50	Need to...	Process Plan
0:51.05	150' distance is there	Domain Plan /Sp
0:51.20	Space columns @25' due to 150'	Domain Decision /Sp

Time h:mm.ss	Description	Activity
0:51.45	Yes, we do space columns @ 25* in extent of lower tower	Domain Evaluation /Sp
0:52.05	They go into 25 story tower	Domain Decision /Sp
0:52.25	150' left in hirise not effected	Domain Evaluation /Sp
0:52.40	Go with 30' in that region for column spacing	Domain Decision /Sp
0:53.10	30' span is very comfortable	Domain Evaluation /St
0:53.25	First to consider in atrium	Process Plan
0:53.35	Columns above atrium, load in these has to be transferred	Domain Plan /St
0:53.55	Calculates length of atrium	Calculation
0:54.20	Use Vierendeel truss system at top of atrium	Domain Decision /St
0:54.35	Column spacing above is 25' is ok for truss	Domain Evaluation /Sp
0:54.55	Can make truss work to transfer load	Domain Evaluation /St
0:55.15	Truss sheds load at edge to columns	Domain Plan /St
0:55.55	Some of columns for high tower also land in atrium	Domain Plan /Sp
0:56.45	Structural system better in steel due to atrium and constraints of atrium	Domain Decision /St
0:57.15	Complexity of shoring for concrete in atrium is bad	Domain Evaluation /St
0:57.40	Basically best to go with steel for atrium	Domain Decision /St
0:58.05	Figure out sizing of steel	Process Plan
0:58.15	Not easy as complex situation around atrium	Domain Evaluation /St
0:58.30	Sizing not around atrium uses the same procedure as done before	Process Decision
0:58.45	Do computer analysis around atrium	Process Decision
0:59.05	Effect of truss, hard to predict	Domain Evaluation /St
0:59.25	Truss will effect what arch, wants to do	Domain Evaluation /A
0:59.40	Wants time to work out on computer	Process Evaluation
1:00.00	Since computer available - use it to get good numbers	Process Decision

Time h:mm.ss	Description	Activity
1:00.25	Asked to sketch out region w/ 25* columns	Sketch
1:00.50	Can't do as said before	Domain Evaluation /Sp
1:01.00	30' only one part (looking only left & right)	Domain Evaluation /Sp
1:01.30	Didn't "see" the problem before	Domain Evaluation /Sp
1:02.05	33.33' give some flexibility	Domain Evaluation /Sp
1:02.20	Last 100' go w/ 33.33' spacing as 100' left	Domain Decision /Sp
1:02.40	Actually - (sees N-S interaction now)	Domain Evaluation /Sp
1:02.55	Not much space left	Domain Evaluation /Sp
1:03.10	More I look at problem, it is nonsens< to go 33.33'	Domain Evaluation /Sp
1:03.25	25' spacing all over is best	Domain Decision /Sp
1:03.40	In conclusion 25' all over due to atrium	Domain Decision /Sp
1:04.05	Use Vierendeel truss to pick up columns above	Domain Decision /St
1:04.30	With 25' spacing maybe reduce the floor to floor spacing 6"	Domain Evaluation /St
1:04.55	Will give some savings on curtain wall, mechanical piping shorter	Domain Evaluation /St
1:05.25	Structural steel definitely can be shallower	Domain Evaluation /St
1:05.50	24" girder would work, but penetration problem	Domain Evaluation /St
1:06.00	Structural steel controlled by duct penetration not by structural calcs.	Domain Evaluation /St
1:07.05	Part b) really requires computer analysis to get good results	Process Evaluation
1:07.35	Asked direction of filler beams	Input
1:07.45	Take your choice - doesn't matter	Domain Decision /Sp
1:07.55	Mechanical could determine direction if can find way to not put HVAC under girders, thus save the space	Domain Evaluation /St
1:08.25	End of Problem 3	

B.2.4 Discussion Answers

Expert 2 - Discussion Transcript

1. ***How important is scale?*** **The design doesn't differ if controlled by gravity, the same system is used and the same bay size. The problem or importance comes in when the building gets taller and the lateral forces get higher and the aspect ratio (height/base) of the building gets higher. The larger base dimension helps lower the aspect ratio. The biggest factor in the building is the height and the aspect ratio.**
2. ***At what stage do you normally interact with the architect?*** **From our own experience at John Portman & Associates we are involved from day one of the project However, not all places are like that - outside consultants do not always interact at such an early stage because the architect has to pay the engineers fee. In our process, the structural engineer is involved with the design architect before any layout is present. We look at the site size, floor plate ideas and interact with all of that We discuss the height of the building and what to consider. This process pays good dividends at the end as everyone gets lots of input to the process and both parties benefit from the interaction.**
3. ***How do the designs for commercial space differ from office space?*** **From my experience, there is not much difference. A thirty foot bay is very desirable for all bays whether the building is for office space, retail space (malls, stores) and also for parking space. Only difference is that retail ;;pace tends to have a chopped up floor for skylights, etc.**
4. ***At what stage do you select material for structural framing?*** **The decision of concrete or steel is at a very early stage in the design process. When we do master planning, there is no structure involved, just a shell to show the owner what the building will look like and maybe a floor layout. After that process we pick the material. The sooner the material is established, the better. People can work toward a goal when the material is selected. The selection is usually made during the first week of the design. The criteria for selecting a material is partly by:**
   - **economic: the structure is one third of the construction cost, so it plays a large part of the cost to the client;**
   - **the way the building is laid out: the span, height of building, configuration of the building, and location of the building.**

   Hotel configurations are natural for concrete as there are plenty of locations for shear walls. The only time a hotel would not be built from concrete is if code problems arise, say due to seismic loads. Concrete is also good for merchantile buildings where no ceilings are used because concrete looks nicer than steel which requires fireproofing. The height is not so much of a factor now for concrete. Maybe if over 1000 feet concrete could have some problems, but they have mixes now to obtain 20,000 psi concrete. There is a building right now coming off the ground in Chicago that is 68 or 70 stories that is concrete.

5. *How does complexity of building geometry affect the design process?* The design process is much more involved. Geometry is a very important part. Symmetry of the building makes it easier to analyze. Complex geometry causes complex structural effects. It used to be almost cost prohibitive to analyze complex geometries, but now with the computer it is easier to do, but still hard to predict and a lot more assumptions have to be made.
6. *Do you idealize complex geometries of buildings into simpler ones?* My first inclination is to answer yes. However, I remember a building done 5 years ago. We had a simplified model and did preliminary analysis and then did detailed analysis where we introduced the complex geometry into the analysis. The two analyses were 40% - 50% different in forces. It was evident that the simple model was not good enough. Some complex geometries can be simplified satisfactorily, but there are some that can not be simplified.
7. *What problems seem to most often cause problems with design?* When major architectural changes are made then everything is affected, we must start from square one with the design. Any changes by others which effect the structure is a big problem. Sometimes the depth of floors can be a big problem or having to stick with some dimensions cause problems.
8. *Please give a description of your experience.* I received a Bachelors from Georgia Tech in 1964 and went into a consulting office for 9 years. I have been with John Portman & Associates for IS years after that. I also took two years leave of absence to work overseas. I received a Masters deyee from Georgia Tech and have registration in several states. My experience has taken me to southeast Asia and most cities in the United States.
9. *What geometric features are key when placing structural systems?* I look for the plate (floor) size, that is the outside dimensions and the aspect ratio. A aspect ratio greater than 1/6, especially when in a seismic zone or where lateral forces are higher cause problems. Lots of reinforcement is needed and you have complex details. I like to maintain 1/500 as a minimum for drift requirements, so that tenants do not suffer comfort problems with building movement

B.3 Expert 3

BJ.I Problem 1

Time h:mm.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:01.10	Bldg. size is 100'x 200' 60' x 30' core centered in middle	Process Evaluation
0:01.35	Need efficient framing plan	Domain Plan /Sp
0:01.45	Who is client & owner & arch.?	Process Plan
0:01.55	Does client want structural optimization?	Process Plan
0:02.00	What are the bldg.'s constraints?	Process Plan
0:02.20	Client is the owner	Input
0:02.45	Good bearing strata is rock	Process Evaluation
0:03.00	Is there a basement in the bldg?	Process Plan
0:03.00	No basements in the bldg	Input
0:03.10	Has the geotech. selected any foundation systems to use?	Process Plan
0:03.30	Foundation systems may govern structural system	Domain Evaluation /St
0:03.45	What is architect's role in bldg.?	Process Plan
0:04.00	Where is bldg. located?	Process Plan
0:04.15	Building is in Pittsburgh	Input
0:04.20	Only have 10' floor to floor	Domain Evaluation /St
0:04.30	For bldgs. in Pittsburgh I would like more floor to floor height	Domain Plan /St
0:04.50	This is very limiting structural depth	Domain Decision /St
0:05.00	How high is ceiling?	Process Plan
0:05.05	Ceiling is 8'	Input
0:05.10	Have only 24" for structural system	Calculation
0:05.30	This eliminates many systems cheapest in Pittsburgh	Domain Evaluation /St
0:05.45	Concrete flat slab is probably only system that would work	Domain Evaluation /St

Time h:mm.ss	Description	Activity
0:06.40	Would like 1.5' - 2' more structural depth	Domain Plan /St
0:06.50	Architect probably wants more than 8* ceilings	Domain Plan /Sp
0:07.15	12' floor to floor is allowed	Input
0:07.40	How is parking handled?	Process Plan
0:07.50	Park around bldg., not inside	Input
0:08.00	Flexible office arrangement desired	Domain Evaluation /Sp
0:08.30	Concrete rare in Pittsburgh, not usually economical	Domain Evaluation /St
0:09.00	What's in the core, elevator, stairs bathrooms? - yes	Process Plan
0:09.20	Core size might vary in size if tenant rents entire floor	Domain Evaluation /Sp
0:09.40	Tenant could have own foyer and services	Domain Evaluation /Sp
0:09.55	How constrained by the architect am I for using the core?	Process Plan
0:10.20	Can use part of core in someway	Domain Decision /Sp
0:10.40	Owner wouldn't want shear walls or x-bracing inside - only use core or perimeter	Domain Decision /Sp
0:11.10	Third option is rigid frame - most expensive	Domain Evaluation /St
0:11.20	How constrained am I? How flexible is office?	Process Plan
0:11.40	What docs the bldg. look like on the outside?	Process Plan
0:11.50	Is it glass box, masonry, granite?	Process Plan
0:12.00	Owner doesn't have idea - he is looking for suggestions	Input
0:12.35	Problem too simplistic	Process Evaluation

Time h:mm.ss	Description	Activity
0:13.00	Many things that decide structural system have costs that can't have dollars associated with them. Such as how big can core be, how open is office?	Domain Evaluation /St
0:13.45	Could do lots of things, but not worth my effort	Process Evaluation
0:14.00	Owner should talk with architect	Process Evaluation
0:14.20	I need more information	Process Evaluation
0:14.35	The most economical lateral system is braced frame for steel	Domain Evaluation /St
0:14.55	Could use shear walls of concrete.	Domain Plan /St
0:15.05	Can't walk or see through shear walls	Domain Evaluation /Sp
0:15.20	Wants these issues defined	Process Evaluation
0:15.30	Owner cost tradeoffs of lat. systems	Input
0:15.50	Once place braced frame in bldg. it cost dollars in flexibility	Domain Evaluation /Sp
0:16.20	I can't do prelim, design in amount of time we have	Process Evaluation
0:16.45	I need a day to do cost	Process Evaluation
0:17.05	Owner would like placement of systems	Input
0:17.25	Very limited for bracing, only in the core or perimeter	Domain Decision /Sp
0:17.45	If rigid frame then place columns architecturally and structurally	Domain Decision /Sp
0:18.05	Where did 100' x 200' plan come from?	Process Plan
0:18.20	Could we go 210' x 90' so as to get a 30' bay?	Process Plan
0:18.35	Does owner not want any columns?	Process Plan
0:18.50	Need columns inside bldg.	Input

Time h:mm.ss	Description	Activity
0:1920	Dimensions must work for other things (i.e., ceilings) besides structural	Domain Evaluation /Sp
0:19.40	Could do rigid frame both ways	Domain Plan /St
0:19.50	Could do rigid one way, and braced framing the other way	Domain Plan /St
0:20.10	May not want bracing all the way down	Domain Plan /St
0:20.20	May want first floor open	Process Plan
0:20.35	Must transfer loads in these cases	Process Evaluation
0:20.45	Loads can go straight down	Input
0:21.05	How sensitive is owner to vibration?	Process Plan
0:21.20	Owner is fairly sensitive to vibration	Input
0:21.30	Different systems have different serviceabilities	Domain Evaluation /St
0:21.45	Open webs - very cheap, but vibration can be a problem	Domain Evaluation /St
0:22.10	This problem is worse in malls	Domain Evaluation /St
0:22.20	If have desks, walls to dampen vibrations then no bad	Domain Evaluation /St
0:22.45	Fireproofing tradeoffs for steel vs. cone.	Process Plan
0:23.00	Not economical to fireproof bar joists	Domain Decision /St
0:23.10	Fireproofing puts constraints on HVAC as openings must be fire dampeners	Domain Evaluation /St
0:23.35	Composite beams & deck is very common	Domain Evaluation /St
0:23.45	Allows the control of vibration	Domain Evaluation /St
0:24.00	Doesn't effect fire issues	Domain Evaluation /St
0:24.15	Structure cost more, but overall cost may be less	Domain Evaluation /St
0:24.35	30' x 30' bay w/12* floor to floor have plenty room for composite beam	Domain Evaluation /Sp

Time hrmm.ss	Description	Activity
0:24.50	On 30* x 30' bay concrete also easy to do	Domain Evaluation /Sp
0:25.20	May have higher ceilings with concrete	Domain Evaluation /Sp
0:25.35	Another sol'n is precast cone, planks	Domain Plan /St
0:25.50	Doesn't make a lot of sense for office	Domain Evaluation /St
0:26.05	Still requires large beams along column lines	Domain Evaluation /St
0:26.20	Least appropriate of all systems discussed	Domain Evaluation /St
0:26.35	In terms of cost, to go rigid frame over braced frame maybe 15% increase in structure	Domain Evaluation /St
0:27.00	Structure is -30% of overall cost of project	Process Evaluation
0:27.20	So really rigid over braced is only 3-5% total cost	Process Evaluation
0:27.45	Least expensive structural not necessarily least overall	Process Evaluation
0:28.00	Would propose that owner think about these issues, and get together w/ arch, & HVAC	Process Plan
0:28.30	See how all needs compare	Process Evaluation
0:28.50	If willing to have 12' floor to floor, the can do anything others want	Domain Evaluation /Sp
	Questions	
0:29.10	How would you layout columns if size is 100'x 200'?	Input
0:20.15	35* is a premium structurally (too big)	
0:30.00	23'centers too close	

Time h:mm.ss	Description	Activity
0:30.20	Probably just as expensive as extra columns needed	
0:30.40	Try 35* & get 12' floor to floor to work	
0:30.55	In 100' direction use 3 spans of 33' or 4 spans at 25*	
0:31.15	Some architects like 5' modules	
0:31.40	Talk with the arch about 25' x 35' spacing	
0:31.50	If can bake bldg. taller maybe do without using any columns	
0:32.10	But then more cost in facade	
0:32.25	This is not the cheapest bldg.	
0:32.50	If know client wants open, then ok	
0:33.20	Irregularities cost money - lose economy of scale when have 30', 35', 30'	
0:34.00	If 35' x 35' and have to raise floor vs. using 30' x 30' and it fits are the tradeoffs to consider	
0:34.25	How did cladding type influence structural system?	Input
0:34.45	Decided if bracing go on exterior	
0:35.05	System can effect type of facade	
0:35.20	If want glass then system effected	
0:35.35	If want most economical - look for place to put in x-bracing or shearwalls	
0:35.50	Could punch holes in those but constrains architectural look	
0:36.30	Cladding not concern for gravity load, but opening do matter	

Time hrmm.ss	Description	Activity
0:36.45	How does paiking in basement effect structural system?	Input
0:36.55	Many new constraints	
0:37.05	Need entrance & exit	
0:37.10	Driving lanes min. dimensions	
0:37.20	Minimum spacing of columns so can park and drive	
0:37.55	Find out what are the alternate parking layouts	
0:38.00	Then how can we fit bldg to it	
0:38.25	Structural system above parking governed by where paiking is, as columns should line up	
0:38.55	Unless want to transfer loads at great cost	
0:39.10	Need to look at parking layout & see what structure can be put in	
0:39.30	Also effects lateral system, shear wall & x-biacing effect driving	
0:39.50	Size of core in basement drives constraints	
0:40.10	Post-tensioned concrete slabs in Pittsburgh are popular	
0:40.30	Good durability	
0:40.40	Slabs may be supported on steel or conc.	
0:40.50	Only 20' to bedrock, we do have deep foundations	
0:41.15	Have caissons (drilled piers)	
0:41.30	More expensive than spread footings	

Time h:mm.ss	Description	Activity
0:41.50	If use parking then no caissons and thus foundation cheaper	
0:42.10	20' depth of parking looks good for 2 layers	
0:42.25	Any other architectural consideration you would liked answered?	Input
0:42.50	Important issues deal with geometry floor to floor, size of bldg. parking layout acceptable column spacing to arch., what kind of facade desired	
0:43.30	If not limited, lots of permutations	
0:43.50	How could multi-story braced bays do for lateral system?	Input
0:44.05	When worked in with facade they are ok	
0:44.20	Would be terrific structurally	
0:44.30	In terms of facade treatment they may cost more	
0:45.10	End of Problem 1	

B*32* Problem 2

Time h:mm.ss	Description	Activity
0:00.00	Reads Problem Statement	Input
0:01.50	30 story bldg. - will use 12' floor to floor height	Process Evaluation
0:02.20	30x12'= 360'bldg	Calculation
0:02.30	300' x 100* plan	Process Evaluation
0:02.40	Many of the things said in previous problem apply here	Process Plan
0:02.55	All comments on structural system for previous problem apply	Domain Plan/St
0:03.10	Biggest change is bldg. much taller	Domain Plan /Sp
0:03.20	Aspect ratio ~ 3.5 to 1	Calculation
0:03.40	Much taller & slender bldg.	Domain Evaluation /St
0:03.45	Maybe harder to control drift	Domain Evaluation /St
0:03.55	May increase relative cost of moment frame relative to braced frame	Domain Evaluation /St
0:04.20	Braced frame even more economical now	Domain Decision /St
0:04.30	30' spacing in long direction	Domain Decision /Sp
0:04.40	35' & 30' spacing in short direction	Domain Decision /Sp
0:05.00	Try to think of something new with this building	Process Evaluation
0:05.20	Mechanical floor is on 15th floor - this isn't unusual	Domain Evaluation /Sf›
0:05.30	Mechanical floor may not be 12' - could put structural stiffeners in there to limit drift	Domain Plan/St
0:06.00	Could put bracing system in mechanical floor if using rigid frame, so as to limit deflection	Domain Plan /St
0:06.30	So have a 15 story frame, a rigid floor & then another 15 story frame	Domain Plan /St

Time h:mm.ss	Description	Activity
0:06.50	I have never done a 30 story bldg.	Process Evaluation
0:07.00	The rigid story would come in 2nd or third iteration, once it has been decided .o use a rigid frame	Process Evaluation
	Questions	
0:07.30	What structural systems would you use to control drift?	
0:07.50	Want to reduce deflection at top of bldg.	
0:08.00	A rigid frame is more flexible & thus has more problems with drift than bracing	
0:08.20	Rigid frame thus requires bigger sections and has a higher cost	
0:08.55	Mellon Bank Bldg. and Oxford Center show comparison. Oxford had braced frame while Mellon had rigid. Oxford appeared much lighter to the eye. This was a drama? ic example of how bracing reduces amount of steel needed.	
0:10.15	How much bracing would you need for this problem?	
0:10.35	Need whole 100* width of bldg.	
0:10.45	Placed at ends of bldg. & at core	

Time h:mm.ss	Description	Activity
0:11.00	Could use all 4 edges of cores or just 2 bents needed - not sure	
0:11.20	4 lines is minimum, 6 maybe	
0:11.35	Discuss serious issues with architect on how bracing effects core	
0:11.45	In E-W direction - lots of room	
0:12.05	Any other differences between this and the other problem?	
0:12.40	Need to evaluate all those issues discusse 1 before for the first iteration	
0:13.00	End of Problem 2	

B33 Problem 3

Time hrmm.ss	Description	Activity
0:00.00	This will be different	Process Evaluation
0:00.10	Reads Problem Statement	Input
0:01.00	12' floor to floor	Domain Decision /St
0:01.10	Building considerably different	Process Evaluation
0:01.20	Much more interesting, more challenging	Process Evaluation
0:01.40	Standard concepts won't work	Process Plan
0:01.45	Need special attention	Process Plan
0:01.55	If have atrium owner not penny conscience	Process Evaluation
0:02.10	Realizes there are two problems	Process Evaluation
0:02.20	Still interesting	Process Evaluation
0:02.30	Building is not a box	Process Plan
0:02.40	2 squares that overlap	Process Plan
0:02.45	2 different heights	Process Plan
0:02.55	Lots of conflicting things	Process Plan
0:03.10	Decide whether bldg. is tied together or not	Process Plan
0:03.20	Where is the joint between the 2 and what is the joint?	Domain Plan /Sp
0:03.30	If tied together how do you handle twist	Domain Plan /St
0:03.55	Core is very small, open offices	Domain Plan /Sp
0:04.05	Core too small to move people	Domain Evaluation /A
0:04.30	200' x:.)0' - twice the plan area of first building, but smaller core	Domain Evaluation /Sp
0:04.50	All things talked about still apply effects on facade, parking, fire protection	Process Evaluation
0:05.15	Without atrium still have bldg. costing more than rectangular bldg. due to complexity	Domain Evaluation /St

Time h:mm.ss	Description	Activity
0:06.05	How would we want to laterally brace bldg.	Domain Plan /St
0:06.25	Rigid frames would work	Domain Evaluation /St
0:06.30	Are they most cost effective	Domain Plan/St
0:06.40	May be only sol'n when talk with the architect, due to visual effects	Domain Evaluation /A
0:07.00	Don't separate 2 bldgs. then there is no expansion joint	Domain Decision /Sp
0:07.20	Intercon lect so bracing can work together	Domain Decision /St
0:07.40	No sliding bearings & those terrible conditions	Domain Decision /St
0:07.55	Don't have core for bracing	Domain Evaluation /St
0:08.00	Don't have core for circulation	Domain Evaluation /Sp
0:08.10	How would core change?	Process Plan
0:08.15	Want bracing on outer corners & core	Domain Plan /St
0:08.30	Leaves inner section open for rental	Domain Evaluation /A
0:08.45	Push bracing out to corners	Domain Decision /St
0:08.55	Sdll tall building, 12 * 25 = 300'	Domain Evaluation /St
0:09.10	Let's see what core really is before continuing	Process Plan
0:09.20	If include atrium	Process Decision
0:09.30	Have to put 10 stories on top of atrium	Process Plan
0:09.45	How to transfer loads in problem	Domain Plan /St
0:10.00	Bay spacing would decide transfer	Domain Plan /Sp
0:10.15	Comer of bldg. is in middle of atrium	Domain Plan /Sp
0:10.25	Pretty significant transfer	Domain Evaluation /St
0:10.40	Multi-story trusses may handle	Domain Plan /St
0:10.55	Even bigger problems due to corner of bldg	Domain Evaluation /St

Time hrmm.ss	Description	Activity
0:11.10	This makes it harder to control drift	Domain Evaluation /St
0:1120	Roof of atrium could be neat	Domain Plan /St
0:11.30	Top floor of atrium as exposed truss system	Domain Plan /St
0:11.45	This would look lacy	Domain Evaluation /A
0:11.55	But significant structure	Domain Evaluation /St
0:12.05	Terrific amount of load coming in there	Domain Evaluation /St
0:12.20	What else could you do in atrium?	Process Plan
0:12.30	Could we move atrium	Domain Plan /Sp
0:12.40	Could we move building - bad location	Domain Plan /Sp
0:12.55	If have open field in Iowa can build anything	Process Evaluation
0:13.10	In most constrained situation you get clever solutions	Process Evaluation
0:13.45	How to make it work	Process Plan
0:13.55	All kinds of things to work & not jeopardize esthetics	Process Plan
0:14.15	If we didn't like all loads to middle of atrium and we couldn't relocate	Domain Plan /Sp
0:14.45	Could be monolithe column in atrium	Domain Plan /St
0:15.00	Unbraced 5 story column pretty sizeable	Domain Evaluation /St
0:15.10	Maybe column is not unbraced	Domain Plan /St
0:15.20	But then not open space - have structural members "flying" through space	Domain Evaluation /Sp
0:15.40	How does this effect architect's "vision"	Domain Evaluation /A
0:15.50	Would save money but what is visual effect	Domain Evaluation /A
0:16.05	Lots of ideas - lots of fun	Process Evaluation
0:16.15	Buildings overlap @ 100* causes problems with 30' bay	Domain Plan /Sp
0:16.35	Would like column line there	Domain Plan /St

Time h:mm.ss	Description	Activity
0:16.45	Could have column set back	Domain Plan /St
0:17.00	My guess is that set back not good for architect	Domain Evaluation /A
0:17.10	Have to divide 100' - 3 @ 33'-4" or4@25'or30\40\30'	Domain Plan /Sp
0:17.25	It is a problem	Domain Evaluation /Sp
0:17.30	Would see sizes change & shift	Domain Evaluation /St
0:17.45	Would give more reasonable bay spacing for architect and engineer	Domain Evaluation /St
0:18.00	Good for first pass, but will change	Process Evaluation
0:18.15	What else can I do with corner in atrium	Domain Plan /St
0:18.25	Can we transfer @ roof of atrium?	Domain Plan /St
0:18.40	If mechanical at roof of 15 story bldg. then can use space to hang middle of 15 story bldg over atrium	Domain Plan /St
0:19.15	Things like that would be interesting	Domain Evaluation /St
	Questions	
0:19.30	What to look at so that 25 story has load reduce on corner	Input
0:19.55	Move core into corner	
0:20.05	Half of core is in atrium so something has to move	
0:20.25	Could there be glass elevators?	
0:20.30	Core must move	
0:20.40	Even when enlarge core, how much of atrium is eaten up?	

Activity h:mm.ss	Time	Description
0:21.00	Maybe load into core instead of comer	
0:21.15	But if core moves maybe not in corner to take load	
0:21.30	Could brace to transfer load away	
0:21.55	Think of other ways to hang things	
0:22.15	Atrium is an expense beyond unrentable space	
0:22.30	Lots of complexity involved	
0:22.40	What I'd like to do, is have from architect answers to the questions	
0:23.00	and have acceptable column spacings	
0:23.10	Have tht core better done	
0:23.20	What can I do in the atrium should be better defined	
0:23.40	Building this size & type has a driving force from the architect, not the economics of the structure	
0:24.05	Premium of structure not as important	
0:24.20	Owner has nontangeable effects that he is paying for	
0:24.40	Architectural details drives more than dollars	
0:24.45	Not that dollars not important	
0:24.55	Building done before had many interactions with arch, on how atrium would look down middle of building	
0:25.30	The atrium did not always have an arch over it	
0:25.45	Once the arch, decided how it looks then do structure	

Time h:mm.ss	Description	Activity
0:26.00	How do we make these arches, tubes, rolled sections work	
0:26.15	Try to make economical to meet architect's solution	
0:26.30	If had to specify to architect what he should strive for, what would your recommendations be?	Input
0:26.50	Find ways to place braced frames	
0:27.10	Spends a lot of money - would work though	
0:27.30	So look how to place bracing to make it look nice	
0:27.45	How to structure atrium so still nice aesthically	
0:27.55	What to do with the core	
0:28.10	How do buildings intersect	
0:28.20	Then have a meeting a week later	
0:28.25	Have several ideas to discuss structural & HVAC requirements for those ideas	
0:28.40	Structural is only one part of the equation to make building work	
0:29.15	Most issues from Problem 1 still apply here	
0:29.40	About all I have to say	
0:29.45	End of Problem 3	

B.3.4 Discussion Answers

Expert 3 - Discussion Transcript

1. *How important is scale?* When the building increases in plan size the core requirements change. More important scale issues are when the height doubles rather than the plan dimensions. Sometimes when a building of small plan dimensions is built, there is a tighter budget and the owner may sacrifice some items that would not be sacrificed in larger buildings, for example, the vibration issues. I do not see changing the plan dimensions from 100' to 200* as big an issue as deciding whether the dimension is 200' or 210' so that a nice bay size is developed.
2. *At what stage do you normally interact with the architect?* From my experience in my own practice, the time that tie architect calls for my services varies. I rarely deal with the owner, but am a subconsultant for the architect Ideally I would like to have problems similar to number three with some details such as site plan, and elevations. This information defines better what the architect is expecting and then the architect and structural engineer can work together to achieve these ideas. By having the architect consult early, I can open up opportunities rather than say you can not do this. The more the architect has defined before the structural engineer is called, the less choice I have. I would like to see this type of interaction but it rarely happens. Usually I am consulted and the columns have been located, the floor to floor height established, the material type selected, and it is my job to size the members.
3. *How do the designs for commercial space differ from office space?* Offices are usually multi-story whereas commercial space is usually spread out. There are more constraints on commercial (retail) space as the spaces are highly visible. A lot of money is spent at entrances and escalators to attract the customer. Everything else is then done very cheaply. This is why shopping malls are usually constructed with bar joists - they are very cheap, but suffer vibration problems.
4. *At what stage do you select material for structural framing?* The material selection occurs very early in the process. The material is selected after the questions I posed earlier have been answered. With these answers various alternate designs using different materials are compared. There relative economies are viewed in terms of not only the structural properties, but also the architectural effect and the HVAC issues. These decisions must be jointly solved, then the building material can be chosen and the design refined. Location of the building is very important in the determination of the construction material.
5. *How does complexity of building geometry affect the design process?* I discussed this in problem three. The more constrained the problem, the more creative the design can be. Also the design process is more interesting when there are many constraints.
6. *Do you idealize complex geometries of buildings into simpler ones?* Engineers always simplify models. This is evidenced by the thoughts given in problem three for the atrium. The solution process takes apart the problem and reconstructs it to solve any problem.

7. *What problems seem to most often cause problems with design?* **The biggest problem is time. Invariably the owner wants the building built and there is never enough time to do it. I am a consultant to the architect and not directly to the owner, so there is less control over the schedule. Usually either the owner or architect changes the schedule which makes the process difficult. When I am called in early to discuss structural systems many difficulties can be avoided which lulps the problems that a change in scheduling can create.**
8. *Please give a description of your experience.* **The tallest building I have designed is 23 stories. I have done all types of structures from family dwellings to tali Apartment buildings. I have used steel, concrete, and timber. Most of my clients are architects. I have not designed any bridges or industrial facilities. Personally, I have worked on approximately 1000 different projects over 10 years. I have been a structural engineer for 13 years.**
9. *What geometric features are key when placing structural systems?* **The corners of buildings, and cores are key places to put structural systems. Also I look for modules that work, like the 30' dimension. There are good places and bad places such as 10' away from a core. The good and bad aspects are not necessarily structural as much as they are architectural concerns. Structural design is a small percentage of the overall process and a small percentage of the total cost. Therefore structural design may be secondary to other concerns.**
10. *What percentage of the total design is structural design.* **The structural design fee is usually 10% of the architect's fee and the architect's fee is 3%-15% of the construction cost.**
11. *How important is symr· etry of the structuralframing?* **Gravity loads are not important except for economy of scale. For lateral loads, symmetry reduces torsion which can be a big problem. Vertical symmetry, that is floor to floor, is very important because if the building is not symmetric, methods to transfer the loads between floors must be developed and these are usually very costly.**

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