U.S. Department of Transportation
Federal Highway Administration

SAN FRANCISCO–OAKLAND BAY BRIDGE PROJECT

PEER REVIEW

DECEMBER 2004

San Francisco–Oakland Bay Bridge Project: Peer Review

DECEMBER 2004

Executive Summary

After the 1989 Loma Prieta and 1994 Northridge earthquakes, the State of California enacted the State Toll Bridge Seismic Retrofit Program in 1997 to improve the safety and reliability of critical transportation infrastructure assets in California. One of the critical elements to successfully finishing the program is completion of the San Francisco–Oakland Bay Bridge (SFOBB) project. This project consists of 16 separate contracts, including the proposed self-anchored suspension (SAS) bridge contract.

Caltrans advertised the SAS contract in February 2003 and opened bids in May 2004. The single bid received (in the amount of $1.4 billion using foreign steel) exceeded the $740 million of funding available for the SAS portion of the SFOBB. The California Legislature was unable to develop a funding package to address the additional cost and the contractor's bid was allowed to expire.

In September 2004, the California Secretary of Business, Transportation and Housing asked the Federal Highway Administration (FHWA) for assistance in moving the SFOBB project forward. FHWA assembled the Peer Review Team (PRT), which convened November 1–5, 2004. The team examined project alternatives identified by Caltrans and assessed the risk that each might not achieve its key objectives. It is important to note that the PRT did not perform any independent analysis of technical issues (seismic performance), environmental documentation, cost estimation, or constructability, but relied exclusively on data presented by Caltrans, the Independent Review Team (IRT), the project design team (T.Y. Lin International/Moffatt & Nichol), and Bechtel. In the risk assessment, the PRT considered the quality and reliability of the data presented on the basis of the design development of the different alternatives, which range from a 100 percent design completion for the current SAS design to less than 5 percent design completion for some of the other alternatives.

Each of the six project alternatives we evaluated provides a solution to the SFOBB problem, but can be affected by uncertainty and associated impacts. These impacts typically affect project cost and schedule, either directly or indirectly. We identified, quantified, and prioritized technical, cost, and schedule; environmental; management; and public acceptance and expectation risks.

The alternatives and their overall impacts follow:

- *Rebid the current SAS design (Alternative 1)*. A small number of SAS bridges have been constructed worldwide. The design is a technological innovation that employs materials of limited availability and requires complex methods of construction. These factors impact construction risk and as a result cost of construction. At the same time, the completeness of its design and environmental approvals mitigate the ability of third parties to delay the project.

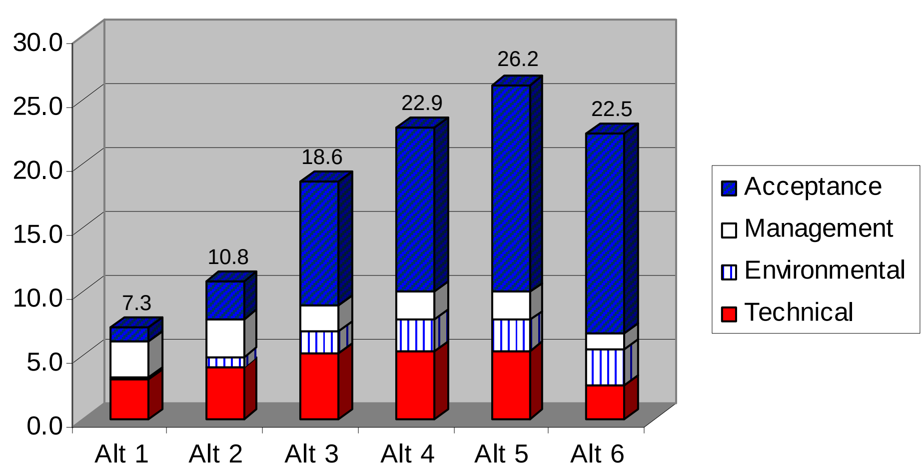
- *SAS with concrete tower (Alternate 2)*. This alternative poses the same risks as Alternative 1 with the additional complication that some minor modifications to the environmental permits may be required.

- *Cable-stayed (Alternatives 3, 4, and 5)*. The construction industry is familiar with this type of bridge, reducing construction risks. A significant pool of suppliers exists for the necessary materials, further reducing risk. If bid as a single large contract, bonding and insurance costs will be significant. All of the cable-stayed alternatives may require revisiting existing permits, which could involve significant effort to resolve concerns.

- *Skyway bridge design (Alternative 6)*. The most significant risks associated with this alternative are community acceptance and revisiting most of the permits. Construction cost would be significantly lower than for the other alternatives because it involves relatively standard bridge construction processes. Because of the construction methods employed, the opportunity to break the work into smaller contracts may arise, thereby reducing the cost of bonding.

Figure ES-1 shows the associated risk scores for each alternative by risk type.

Figure ES-1. Summary of Risk Scores by Alternative



The selection of a preferred alternative is a matter of trading risk for expected cost and schedule benefits. In essence, the State of California's tolerance for risk should be the deciding factor in selection. The results of this analysis provide the State's leadership with the information necessary to make that decision.

During the course of the study, we identified several potential actions that Caltrans might consider to enhance the probability of successful project completion. They generally apply across all alternatives, and we enumerate them in Chapter 4.

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Chapter 1
Introduction

In response to the 1989 Loma Prieta and 1994 Northridge earthquakes, the State of California enacted the State Toll Bridge Seismic Retrofit Program in 1997 to improve the safety and reliability of its critical transportation infrastructure assets. One of the critical elements in finishing the program is completion of the San Francisco–Oakland Bay Bridge (referred to in the rest of this report as SFOBB) project which consists of 16 separate contracts. Each of these contracts is being bid, awarded, and administered separately.

The California Department of Transportation (Caltrans) advertised the SAS contract in February 2003 and opened bids in May 2004. The single bid received in the amount of $1.4 billion[1] exceeded the $740 million of funding available for the SAS portion of the SFOBB. The California Legislature was unable to develop a funding package to address the additional cost, and the contractor's bid was allowed to expire.

In September 2004, the California Secretary of Business, Transportation and Housing (BTH) asked the Federal Highway Administration (FHWA) for assistance in moving the SFOBB project forward. FHWA asked LMI to facilitate the SFOBB peer review team (PRT) in independently assessing the risks of the options available to BTH in choosing the best value for providing a safe, reliable structure to replace the existing Bay Bridge. This report presents the results of that assessment.

SAN FRANCISCO–OAKLAND BAY BRIDGE PROJECT

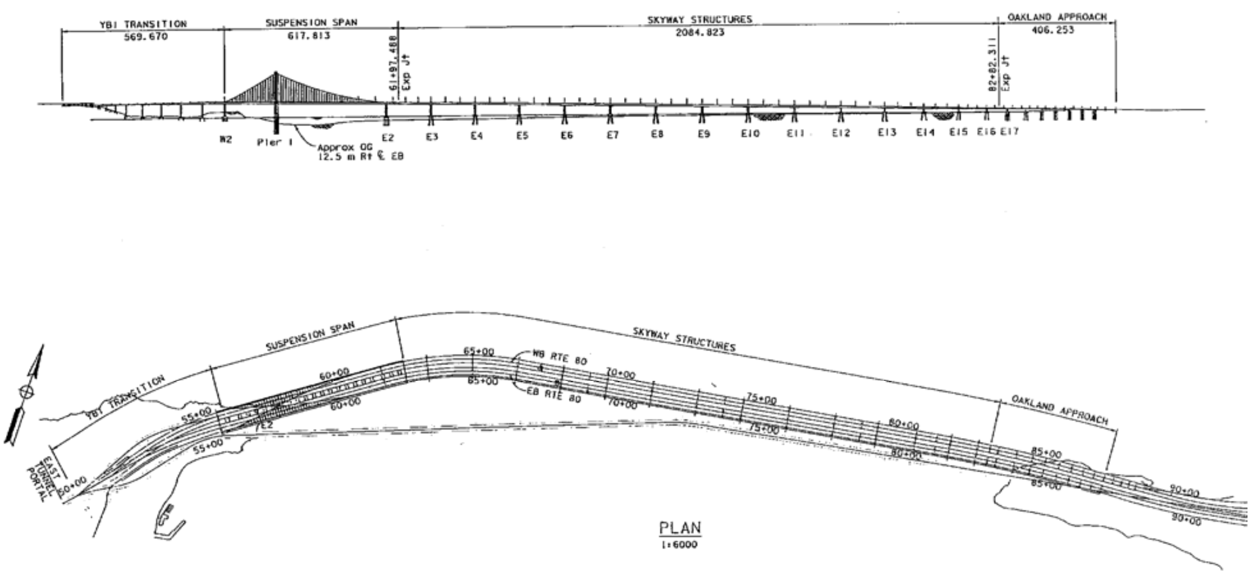
In August 1997, Senate Bill 60 (SB 60) was signed into law. This bill provided a funding package for replacing the east span bridge and increased tolls at all State-owned toll bridges in the Bay Area. Figure 1-1 shows the limits of the bridge replacement project, which replaces the existing bridge from Yerba Buena Island to the Port of Oakland.

[1] The SAS bid was for $1.4 billion using foreign steel. The bid with domestic steel was $1.8 billion. Throughout the remainder of this report $1.4 billion is used for the cost of the SAS.

Figure 1-1. Limits of San Francisco–Oakland Bay Bridge Project

In 1997, a joint venture of T.Y. Lin International and Moffatt & Nichol was selected to design the SFOBB on the basis of several Engineering Design Advisory Panel (EDAP) and Caltrans criteria, including specific performance criteria for a "lifeline" structure and 150-year design life.[2] Figure 1-2 shows the profile and plan views of the project, a self-anchored suspension bridge.

Figure 1-2. Bridge Design Profile and Plan Views



In February 1998, the Metropolitan Transportation Commission adopted the task force recommendations for inclusion of a 15-foot-wide bicycle and pedestrian path (Figure 1-3).

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[2] Design of the new bridge structure was based on a set of 17 finance, design, and planning recommendations prepared by the EDAP and approved by the Metropolitan Transportation Commission Bay Bridge Design Task Force.

Figure 1-3. Current Bridge Design—Two Structures with Integrated Pedestrian and Bicycle Path

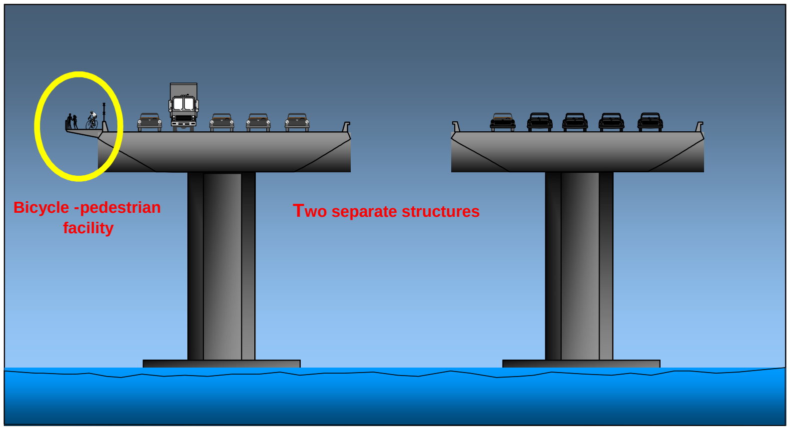


Figure 1-4 shows a computer-generated view of the completed SAS signature bridge.

Figure 1-4. Computer-Generated View of SAS Bridge

FHWA PEER REVIEW TEAM

The PRT, assembled by FHWA and convened November 2004, was tasked to review the alternatives available to meet the objectives of the SFOBB project and report its findings to the BTH Secretary. To perform this risk assessment study, the PRT established operating principles to serve as the framework for the analysis. Because the engineering alternatives were already extensively analyzed and a short time was allotted for its review, the PRT decided to work within the scope of existing reports and analyses and not attempt to identify alternatives beyond the six already identified by Caltrans. Also, because of the complexity and importance of the decision, the PRT sought diverse and differing opinions on the alternatives and their impacts. The PRT strove to provide value-added information to the decision-making process, but not impinge on the State's role as the primary decision maker. The PRT charter was not to select a preferred alternative, but to evaluate each alternative and identify the associated risk.

The PRT was a multidisciplinary team experienced in large-scale bridge and highway projects from the state, federal, and private-sector perspectives. It was led by FHWA, which conducted the review at its Sacramento office. (Appendix A contains biographies of PRT members and their contact information.) PRT members are as follows:

- Gene Fong, P.E., FHWA (team lead)
- Nancy Bobb, P.E., FHWA
- Joan Bollman, FHWA
- William Crawford, P.E., Nevada DOT
- John Dewar, FHWA
- Leland Dong, FHWA
- Charles Dwyer, P.E., South Carolina DOT
- Brett Gainer, J.D., FHWA
- Michael Lewis, Massachusetts Turnpike Authority
- M. Myint Lwin, P.E., S.E., FHWA
- Harold Peaks, FHWA
- George R. Poirier, P.E., FHWA
- Sara M. Purcell, J.D., FHWA
- Cliff Schexnayder, Ph.D., P.E., Arizona State University
- Frieder Seible, Ph.D., P.E., University of California, San Diego
- Daniel C. Wood, P.E., FHWA
- Rovane Younger, California State University

- LMI team members
  - Bill Moore, Ph.D., P.E.
  - John Dettbarn, D.Sc., P.E.
  - Hugh Reams, P.E.
  - Doug Gray, P.E.

CALTRANS INITIATIVES

Caltrans has aggressively managed the SFOBB process from its inception, guiding the project through extensive technical evaluation and testing and a complex process of collaboration, review, and public acceptance. At every step, it has attempted to maximize the best value for the State of California while recognizing competing interests and objectives. The overriding goal of Caltrans has been to ensure that the public health and safety concerns associated with having a highly reliable bridge from San Francisco to Oakland are adequately addressed.

Caltrans is currently pursuing two initiatives, in addition to its own analyses, to provide State decision makers with adequate information to make an informed decision. The first is the work of the independent review team (IRT), which is focused on assessing the technical and cost issues associated with the alternative solutions. The second is the evaluation of the PRT, the subject of this report.

REPORT ORGANIZATION

This report contains four chapters and supporting appendices organized as follows:

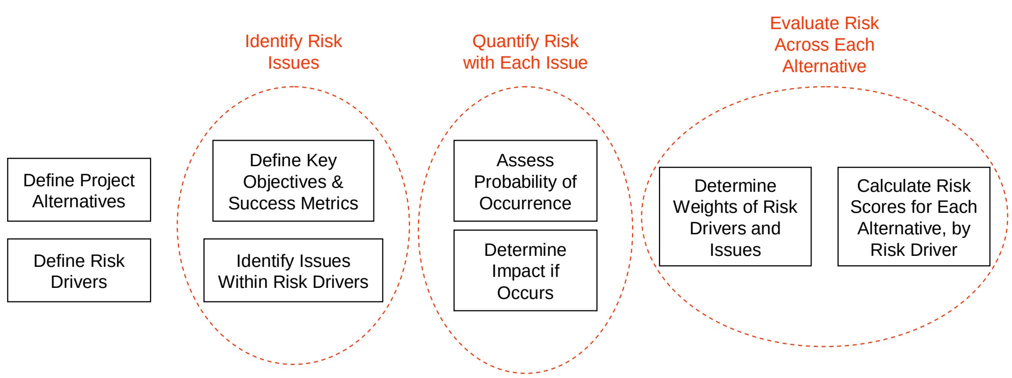
- Chapter 2 presents the study approach.
- Chapter 3 describes the alternatives considered.
- Chapter 4 gives our conclusions.
- The appendices detail our approach and provide supporting information.

Chapter 2
Technical Approach

This chapter describes the technical approach the PRT used to assess the risk of the east span of the SFOBB project for each of the six alternatives. We review our risk assessment approach, addressing the steps in the analysis in the order performed. Appendix B describes our general risk assessment approach, and Chapter 3 describes the alternatives considered.

In conducting this risk assessment, the PRT—a group of experts empanelled by FHWA—identified and assessed the risks associated with replacing the east span of the Bay Bridge. Figure 2-1 shows the approach we used, and the sections that follow describe it.

Figure 2-1. Study Approach



RISK DRIVERS

To evaluate the six different alternatives, we investigated four primary types of risk drivers that have the greatest influence on the risk of the SFOBB project not meeting its stated objectives:

- Technical, cost, and schedule
- Environmental
- Management
- Acceptance and expectation.

Technical, Cost, and Schedule

Technical risks impact project scope, increase project cost or schedule, reduce safety margins, or reduce the quality of the final product. They are commonly regarded as events that have an overarching influence on many elements of the project, as opposed to the typical uncertainty associated with specific work activities (and reflected in cost risks). If these events occur, they can impact the project assumptions and basis. Although technical risks often cause increases to project costs and schedule, they also may affect the safety, quality, and manageability of a project. They may cause the project to become more complex, requiring much more interface and coordination than originally planned. Technical risks generally can be managed and mitigated to some degree; they do not include unforeseen events such as natural disasters.

Cost risks are primarily uncertainty in the components that roll up to the total project cost. They reflect the variability of the cost estimating data, due to such factors as the completeness of design, errors or omissions in the cost estimate, inflation effects and uncertainty, uncertainty in the site conditions, quantity variances, worker productivity, and construction complexity. These uncertainties are commonly accounted for through traditional contingency.

Schedule risks impact the schedule of individual activities and the project as a whole. Ultimately, schedule delays affect the costs. The design process is very complex, and its many steps create opportunities for delay. Seismic, aerodynamic, and geotechnical testing may become iterative, possibly requiring additional analysis on the basis of initial results. If materials are late, work crews may be idle. In extreme instances, contractor demobilization may be necessary, which increases costs. If schedule delays impact elements of the critical path, the project will not be completed on time. This has serious implications. The contractor will continue to incur fixed overhead expenses. Funding may be exceeded, causing project shutdown until additional funding is secured. Other projects in the area may be impacted by a schedule delay.

Environmental

Environmental risks potentially impact the project's cost, scope, or schedule. Although some regulatory re-consultation may be involved, the primary environmental risk driver is related to the permit process, where alternatives cause potential changes to environmental conditions mentioned in the approved environmental impact statement (EIS). These potential changes cause the individual permit processes to be reviewed and potentially reopened for review and new approvals. Environmental risk carries a secondary impact in that reopening a previously completed approval process gives everyone with a project concern the chance to significantly delay the project or increase its cost to address their concern, regardless of whether it is really environmentally related.

One element of any decision regarding the SFOBB deserving of separate mention is the risk of litigation associated with the various design alternatives. In the opinion of the PRT, this risk is inextricably linked to the environmental issues associated with each of the various options. This is because the environmental—National Environmental Policy Act (NEPA)—process would be the most probable legal avenue of attack for any party opposed to the selection of a design option other than the SAS (whether or not that opposition actually had anything to do with an environmental concern). In the opinion of the PRT, the more any selected option differs from the SAS, the more likely NEPA litigation will be used to oppose the selection. Accordingly, the decision to advance any alternative other than the SAS must be made in light of the potential for delay caused by litigation.

The PRT does not believe that NEPA would require a supplemental environmental impact statement (SEIS) should any of the design alternatives be selected. This is because the changes to piers and other impacts of the various alternatives, when analyzed in the context of the overall SFOBB project, simply would not constitute a significant impact to the environment not already addressed in the final EIS—the determining factor under NEPA.[1] Nevertheless, performing an SEIS may forestall litigation or make winning easier—though it would take time, money, and effort to do so. Litigation would carry with it the risk of prolonged delay, particularly in the (relatively) unlikely event that a plaintiff succeeded in obtaining an injunction against further construction of the project pending completion of an SEIS to the court's satisfaction. Therefore, the decision maker would have to weigh the costs of pursuing additional NEPA work against the potential cost and delay of litigation before advancing any alternative to the SAS.

Management

The management risk driver includes the capabilities and competencies of both the owner and contractor organizations to effectively manage the planning, design, construction, and operations and maintenance of the bridge structure and associated infrastructure assets. Experience with specific types of bridges; organizational structure; engineering, procurement, and construction management business processes; experience with stakeholders and communication management; and contractor stability, bonding, and insurance define this risk area.

Acceptance and Expectation

This risk driver includes issues associated with public trust, political advocacy of special interest groups, and managing expectations of key stakeholders in the project process. Because this is a public project, obtaining public approval is critically important to its success. For the SFOBB project, public input on the

[1] A NEPA reevaluation, however, would be required for any design option other than the steel-tower SAS. A reevaluation is an internal federal agency document intended to determine whether an SEIS is required (23 CFR 771.129). This type of document would involve much less time and effort to produce.

structural, environmental, and aesthetic adequacy of the alternatives will drive the project risks. As with all public-sector projects, some stakeholders possess more political influence than others; therefore, maintaining equity among these stakeholders is important. Maintaining public trust is also important for decision makers since failure to do so will undermine future decisions in other areas.

Risk Issues

We identified specific issues associated with each risk driver and discussed the sources and nature of the risks and the uncertainty associated with each risk. A complete list of risk issues is presented in Appendix C.

Key Objectives and Metrics

Once we determined the risk drivers and associated issues, we needed to define the condition for which risk was being determined. To do so, we identified key objectives and success metrics for the SFOBB project. Caltrans has stated that to be successful, the project must provide the best value for the public (safe, aesthetic, and cost-effective). To do so, it must

- meet seismic performance standards,
- be completed within the original time frame (2012)—any time delay is a problem because the bridge structure is a lifeline facility and required in the event of a seismic event,
- be cost-effective,
- be publicly acceptable,
- be constructible and biddable, and
- meet environmental and regulatory requirements.

A metric was selected for each of these key objectives, and we determined the value of that metric for each alternative. Chapter 4 provides the matrix of success metrics, which is used as the basis for establishing risk. The objective of our analysis was to determine the risk that an alternative would not meet its success metrics.

Quantification of Risk Issues

The next step in the process is to measure and quantify the risk issues within each risk driver. This entails assessing the probability that the risk issue will have an outcome that will be detrimental to the project and the impact if that outcome occurs.

We evaluated each risk issue within each risk driver and its characteristics to gauge (1) the probability (*P*) that an event would impede the SFOBB project from meeting its goals, and (2) the impact (*I*) should such an event occur. The risk (*R*) magnitude was then calculated as the product of probability and impact, which can be represented mathematically by

$$R_i = P_i \times I_i,$$

where *i* designates the risk issue. Appendix B details the risk assessment approach.

RISK ASSOCIATED WITH EACH PROJECT ALTERNATIVE

We then evaluated the risk associated with each project alternative. Since each issue does not have the same effect on risk, we weighted each issue to reflect its influence on the total risk at the risk-driver level. Determining the relative influence of each issue is by necessity somewhat subjective. No quantitative measures exist for the importance of each issue to success at the risk-driver level or, for that matter, at any level. The PRT members (subject matter experts familiar with the project and its alternatives) made expert judgments on the importance of the identified issues.

We used the analytic hierarchy process (AHP) to determine the appropriate weightings. In a similar fashion, the weights across each of the risk drivers were calculated. Once this was done, the weights for the risk drivers and issues were applied to the scores calculated in the risk issues quantification phase above. Appendix C details these steps, and Chapter 4 presents the results of this analysis.

Chapter 3
Alternatives

We used the six alternatives identified by Caltrans as the basis for this review. These alternatives are described in the following sections:

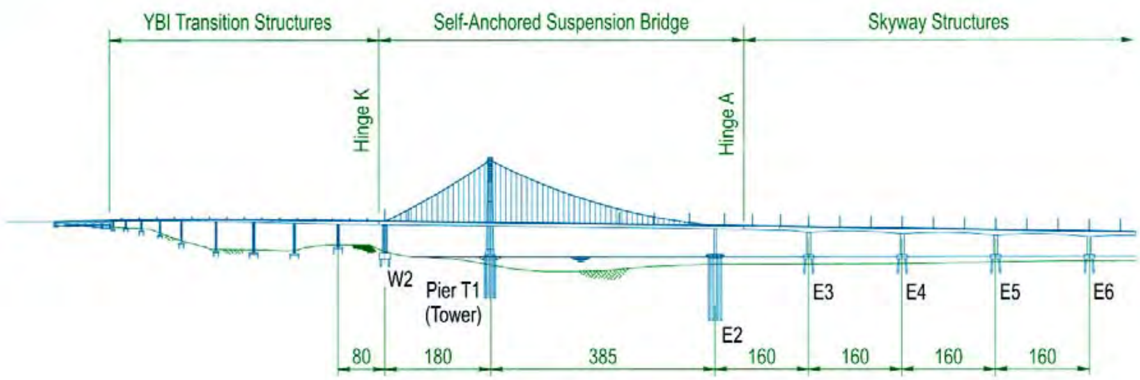
- Alternative 1—SAS Rebid
- Alternative 2—SAS with Concrete Tower
- Alternative 3—Single-Tower, Asymmetric Cable-Stayed Bridge
- Alternative 4—Single-Tower, Symmetric Cable-Stayed Bridge
- Alternative 5—Two-Tower, Symmetric Cable-Stayed Bridge
- Alternative 6—Extended Skyway.

Alternative 1—SAS Rebid

This alternative repackages the original SAS bridge solicitation (which had only one bidder). The new solicitation incorporates the 26 separate contract amendments (developed during the bid preparation phase for the original solicitation) and several known design improvements. The plans, specifications, and estimates (PS&E) are approved, completed, and ready for advertisement.

As designed, construction comprises four basic phases: steel tower, steel orthotropic deck on temporary towers/cables (falsework), cable erection, and connecting the orthotropic deck to cable using premeasured suspenders. The SAS design provides for a 385-meter clear span over the shipping channel (Figure 3-1). Since this SAS bridge contract is designed to fully integrate with ongoing and future contracts, Alternative 1 does not impact the active skyway, E2/T1 foundation, or W2 foundation contracts. Existing environmental studies, approvals, permits, etc., should remain in effect.

Figure 3-1. SAS Rebid Alternative



Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

Available funding ($740 million) for this alternative was not adequate to meet the single bid submitted ($1.4 billion using foreign steel and $1.8 billion using domestic steel). Removing the Buy America provisions through de-federalization may increase the number of bidders, and potentially reduce costs. However, the actual outcome is unpredictable. The Caltrans current working estimate for the project is on the order of $1.2 to $1.4 billion, which exceeds the available funding. This design requires a legislative change and an increased funding package.[1]

Alternative 2—SAS with Concrete Tower

The design for Alternative 2 is very similar to Alternative 1, but the steel tower is replaced by a concrete tower (Figure 3-2).

Figure 3-2. SAS with Concrete Tower

Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

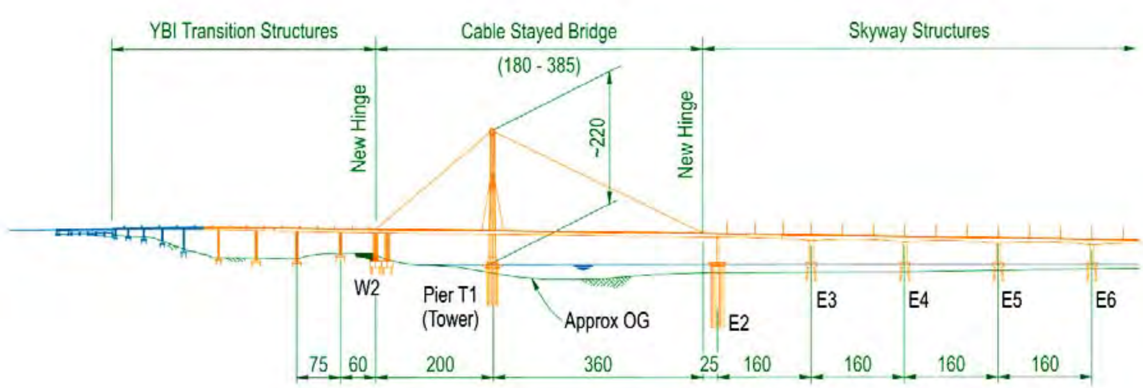
[1] Current legislation requires the SAS design with available funding of $740 million.

This alternative will require additional design to include a change to the T1 foundation contract. To support the concrete tower, the Pier T1 footprint may increase and may require a different piling number and pattern from that currently under contract. In addition, the connection of the concrete tower to the pile cap designed for the steel tower currently under contract is complex and will need significant design and testing. Due to the weight of the composite deck construction, the main cable will require redesign and the E2 and W2 foundation construction contracts are impacted. It has no impact on the skyway.

Alternative 3—Single-Tower, Asymmetric Cable-Stayed Bridge

This alternative changes the type of bridge for the long span portion from an SAS bridge to a cable-stayed bridge with asymmetrical front and back spans. This option provides a look similar to that of the SAS and maintains the 385-meter clear span over the width of the shipping channel (Figure 3-3).

Figure 3-3. Single-Tower, Asymmetric Cable-Stayed Bridge



Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

The structural differences between this cable-stayed alternative and the SAS alternatives include increasing the tower height approximately 60 meters to produce an efficient bridge. There are two possible locations for the hinge in the vicinity of pier E2. For the purpose of analysis we assumed that the hinge for Alternative 3 would be located as shown in Figure 3-3. The tower material would be concrete. To support this concrete tower, the Pier T1 footprint may increase and may require a different piling number and pattern from that currently under contract. In addition, the connection of this larger concrete tower to the pile cap designed for a steel tower is complex and will need significant design and testing. Seismic demands are resisted by Pier W2, which may require an increase in footprint. Depending on the final design, this additional Pier W2 work might require some incursion into the bay at the shoreline or additional impacts on Yerba Buena Island, which could become more problematic if environmentally sensitive or historic areas are affected. The bridge deck changes from an orthotropic box girder to an open composite section, and skyway frame 1 changes from a 4-span to 5-span structure. The existing skyway foundation system may require modification to support the moved hinge and additional span.

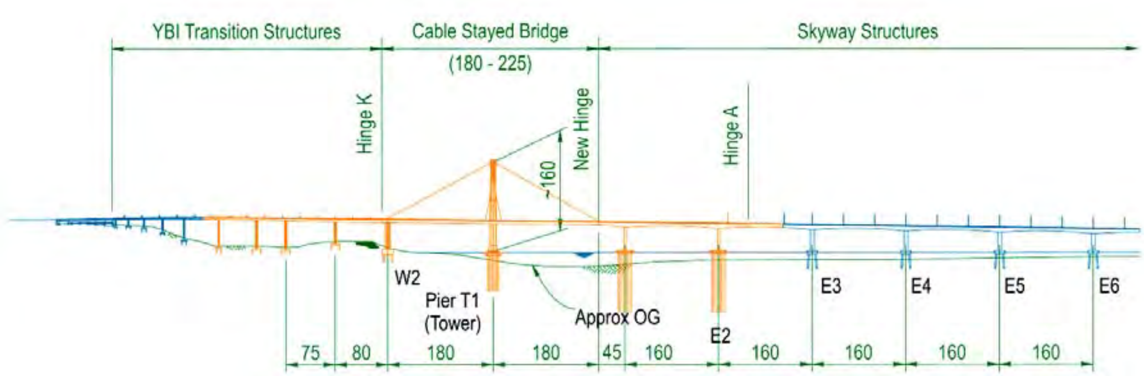
The response of this structure to a significant earthquake event (SEE) is uncertain; some analysis indicates the mass of the structure may have to increase by 30 to 50 percent to provide adequate earthquake response. If this mass increase is realized, further changes to the piers may be required. The connection of the open composite deck and the skyway is very complex and will require considerable design effort. This design has not undergone the extensive wind studies performed on the SAS design. The life span of the composite deck structure is also a concern with respect to the 150-year design life of the bridge.

This alternative may require some environmental amendments and additional permitting because of the changes to the existing foundations. If the final design of Pier W2 involves an incursion into the bay or Yerba Buena Island impacts, the environmental requirements could increase. Any redesign will require time and may impact the schedule. Public acceptance is unknown. Although the cable-stayed span has approximately the same span length and general appearance as the SAS alternative, its reception as a suitable substitute from the aesthetical perspective is uncertain. The increased tower height also violates the original design condition that the new bridge not be taller than the existing suspension span towers on the San Francisco to Yerba Buena Island span.

Alternative 4—Single-Tower, Symmetric Cable-Stayed Bridge

This alternative changes the type of bridge for the long span portion from an SAS bridge to a cable-stayed bridge with symmetrical front (180-meter) and back (225-meter) spans. This approach provides a look similar to that of the SAS but reduces the span over the width of the shipping channel from 385 meters to 225 meters to develop the symmetrical spans (Figure 3-4).

Figure 3-4. Single-Tower, Symmetric Cable-Stayed Bridge



Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

The structural differences between this cable-stayed alternative and the SAS alternatives include a concrete tower at the same height as the SAS design. To support this concrete tower, the Pier T1 footprint may increase and may require a different piling number and pattern from that currently under contract. In addition, the connection of the concrete tower to the pile cap designed for the steel tower is complex and will need significant design and testing. The 160-meter tower and symmetrical bridge drive the clear span availability over the channel. With the reduced clear span, a new Pier E2A (similar to Pier E2 in design) will be required in the bay west of Pier E2. The skyway will extend from the east to this new Pier E2A. The bridge deck changes from an orthotropic box girder to an open composite section.

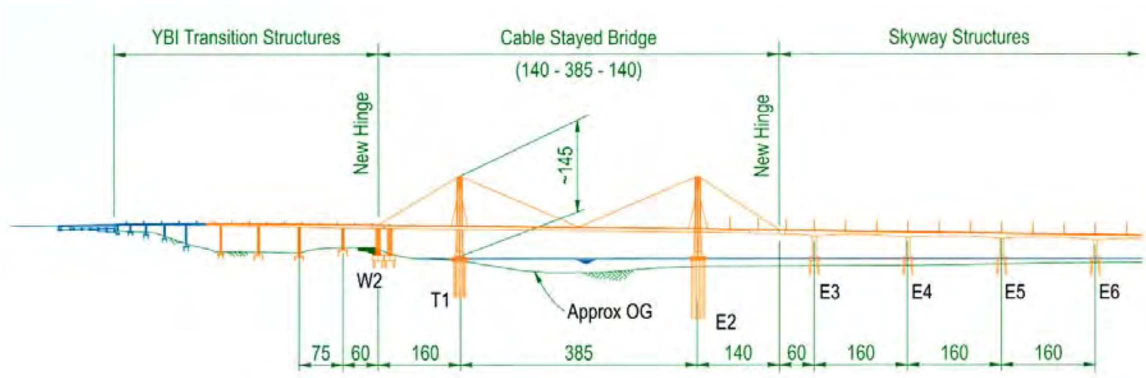
The response of this structure to an SEE has not been analyzed. This design's response to an SEE involves some structural concerns, and some solutions to these concerns may increase the mass, further changing the behavior of the structure. The connection of the open composite deck and the skyway is very complex and will require considerable design effort. The life span of the composite deck structure is also a concern.

This alternative would likely require an environmental amendment and additional permitting because of the changes to the existing foundations and the addition of a new pier. Additional bay fill, dredging, and pile driving would likely be required, resulting in additional permitting issues. Any redesign will require time and likely impact the schedule. Public acceptance is unknown since the symmetrical cable-stayed bridge has a reduced clear span and departs from the proposed signature shape in both size and proportion from the SAS design. The reduced channel width will likely raise concerns with the Port of Oakland and the Coast Guard.

Alternative 5—Two-Tower, Symmetric Cable-Stayed Bridge

This alternative changes the type of bridge for the long span portion from a single SAS bridge to two cable-stayed bridge spans with symmetrical front and back spans. This cable-stayed approach combines the symmetrical cable-stayed bridge form with the 385-meter clear span over the width of the shipping channel (Figure 3-5).

Figure 3-5. Two-Tower, Symmetric Cable-Stayed Bridge



Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

The structural differences between this cable-stayed alternative and the SAS alternatives include two 145-meter concrete towers instead of the single 160-meter tower in the SAS design. The twin symmetrical spans and channel location dictate the location of the two tower piers, and neither corresponds to the existing pier T1 and E2 locations. Pier T1 and E2 will both need to be relocated approximately 40 meters west of their current locations. The Pier T1 footprint may increase and may require a different piling number and pattern from that currently under contract. Pier E2 is currently designed to support the twin roadways of the skyway and will have to be redesigned to support a single tower, ending up similar to the redesigned Pier T1. The Pier W2 footprint will increase. Selection of this alternative would require termination of the existing T1/E2 contracts. As with the other cable-stayed designs, the connection of the concrete towers to the pile caps designed for a steel tower is complex and will need significant design and testing. The bridge deck changes from an orthotropic box girder to an open composite section.

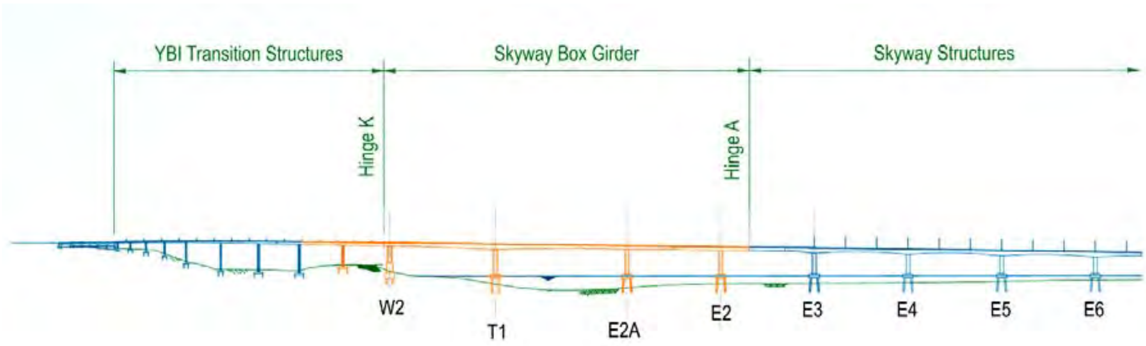
The response of this structure to an SEE has not been fully analyzed. This design's response to an SEE involves some structural and settlement concerns, and some solutions to these concerns may increase the mass, further changing the behavior of the structure. The connection of the open composite deck and the skyway is very complex and will require considerable design effort. The life span of the composite deck structure is also a concern.

This alternative would likely require an environmental amendment and re-permitting because of the changes and relocation of the existing foundations. Additional dredging and pile driving would likely be required, which affect the permit issue. Any redesign will require time and likely impact the schedule. Public acceptance is not likely because the twin cable-stayed bridge departs from the design guidelines of a single tower and the proposed signature shape. The Port of Oakland and Coast Guard will likely raise concerns because this relocates the channel centerline by approximately 40 meters.

Alternative 6—Extended Skyway

This alternative would extend the existing skyway to Yerba Buena Island. The skyway alternative is not a signature span, but consists of a simple box girder design, which presents fewer design and construction challenges than other alternatives (Figure 3-6). The skyway is widely regarded as the least expensive alternative.

Figure 3-6. Extended Skyway



Source: *San Francisco–Oakland Bay Bridge, East Span Seismic Safety Replacement Project*, Presentation to FHWA-PRT, Prepared by T.Y. Lin International, Moffatt & Nichol Joint Venture, November 2, 2004.

The skyway provides a proven cantilever superstructure construction and deep pile foundations. It would require an additional deep-water pier (E2A) closer to the shipping channel and modified foundations at T1 and E2. The skyway and W2 may have compatibility issues. Selection of this alternative would require termination of the existing T1/E2 contracts. Although an extension of existing work, the skyway will require redesign of the hinges on the existing skyway. The design utilizes concrete to a large extent; steel availability is therefore less of an issue.

The skyway alternative would likely require environmental amendments and additional permitting because of the changes to existing foundations and addition of a new one. Additional bay fill, dredging, and pile driving would be required, all of which affect the permit issue. It requires redesign, which may also impact the completion schedule. The acceptance of this design is unknown since it represents a radical change from the SAS signature concept embraced by the public.

This alternative would use a proven construction process. It may also be possible to use multiple construction contracts, thereby lowering the risk to any particular contractor with a potential reduction in bonding costs.

Chapter 4
Conclusions

This chapter presents the results of the PRT's risk analysis. We discuss the key objectives and success metrics, summarize the results, present the results of a sensitivity analysis, and offer actions for Caltrans consideration.

KEY OBJECTIVES AND METRICS

To provide a baseline for analysis, the PRT quantified the key objectives and success metrics (described in Chapter 2) for each bridge alternative.[1] The resulting matrix (Table 4-1) shows the similarities and differences between the alternatives with respect to seismic lifeline reliability, cost, schedule, public acceptance and expectations, constructability and biddability, and environmental considerations.

Table 4-1. SFOBB Key Objectives and Success Metrics

Objective	Alternative					
	1	2	3	4	5	6
	Repackaged SAS	Redesigned SAS, concrete tower	Redesigned cable-stayed: Single tower, asymmetric	Redesigned cable-stayed: Single tower, symmetric	Redesigned cable-stayed: Two tower, symmetric	Extended skyway
Seismic lifeline reliability	High	High	High	High	High	High
Cost ($ billion)						
T.Y. Lin [a]	1.2–1.4	1.2–1.4	1.1–1.5	1.0–1.3	1.2–1.5	0.8–1.0
Bechtel	1.7–1.8	—	1.5–1.7	—	—	—
IRT	1.6–1.7	—	0.9–1.1	0.7–0.9	0.5–0.7	—
Schedule						
T.Y. Lin	2011	2012	2013	2013	2013	2012
IRT	—	—	2011	—	2010	—
Acceptance and expectations	Known	Partially known	Unknown	Unknown	Unknown	Unknown
Constructability and biddability	Difficult	Difficult	Moderate	Moderate	Moderate	Routine
Environmental risk	None	Minor	Minor/ moderate	Moderate	Moderate	Moderate

[1] In conducting our analysis, we used available briefings and studies prepared by Caltrans, T.Y. Lin International/Moffatt & Nichol joint venture, Bechtel Infrastructure Corporation, and the IRT. The PRT did not analyze the adequacy or validity of these detailed cost and schedule elements.

[a] These costs include the costs required to modify the E2/T1 and W2 contracts.

The difference in cost and schedule estimates was considered when the team evaluated the risk of each alternative.

Assessment Results

Each of the six project alternatives evaluated in this study can be affected by uncertainty and associated impacts. These impacts typically affect project cost and schedule, directly or indirectly. The objective of the PRT analysis was to assess the risk (probability and impact) that a particular alternative will not achieve the objectives and success metrics. We identified, quantified, and prioritized the technical, cost, schedule, environmental, management, and public acceptance and expectation risks to investigate their effects.

Table 4-2 summarizes the results of the PRT risk assessments for all alternatives. Appendix C contains detailed risk scores and discusses the analysis for each alternative. It describes the basis for the probability and impact scores we assigned to each issue and how the scores translate to a total risk score for the alternative.

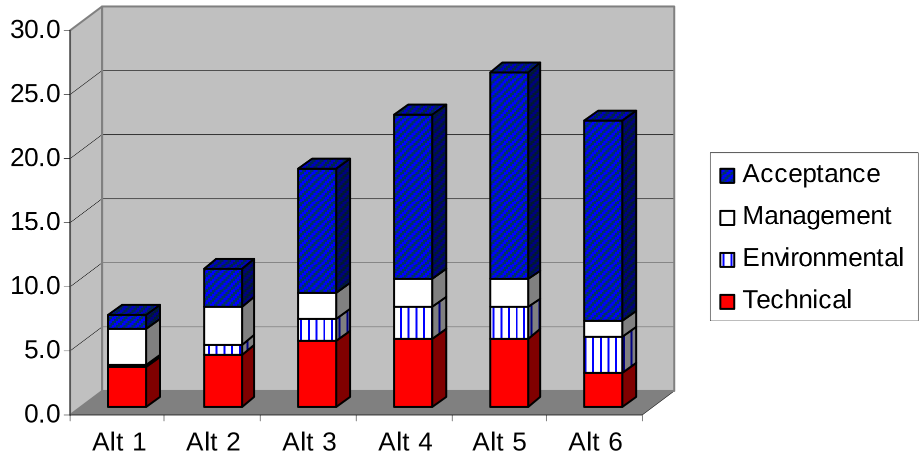
Table 4-2. Summary of Risk Assessment Results

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	3.2	4.1	5.2	5.4	5.4	2.8
Environmental	0.1	0.8	1.7	2.5	2.4	2.7
Management	2.9	3.0	2.1	2.1	2.2	1.3
Acceptance and expectations	1.1	3.0	9.6	12.8	16.2	15.7
Risk total[a]	7.3	10.8	18.6	22.9	26.2	22.5

[a] The columns may not add up properly due to rounding of individual risk issue values.

The SAS designs (Alternatives 1 and 2) have the lowest overall relative risk compared with Alternatives 3, 4, 5, and 6. The cable-stayed bridge designs (Alternatives 3, 4, and 5) have significantly more risk than Alternatives 1 and 2. The skyway bridge design (Alternative 6) has more risk than Alternatives 1, 2, and 3, but less risk than Alternatives 4 and 5. Figure 4-1 graphically summarizes the risk assessment for each of the alternatives.

Figure 4-1. Summary of Risk Assessment for Six Alternatives



The risk score can be loosely interpreted as the relative likelihood of cost and schedule growth. For example, in selecting the skyway bridge design, meeting the cost and schedule goals may be in jeopardy since the public may not initially accept that design concept and require additional input and public outreach. This would likely equate to increased project costs and schedule slippage if the public concern was manifested as opposition to aesthetic, environmental, or other issues. Alternatively, selecting the SAS rebid (Alternative 1) has a greater probability of meeting cost and schedule goals since the risk drivers exhibit very limited risk.

The selection of a preferred alternative becomes a matter of trading risk for expected benefits (success metrics) where the benefits are cost and schedule related. The skyway (Alternative 6) has attractive potential construction cost savings, but there is significant risk that those benefits may not be realized. The same is true to a lesser extent for the cable-stayed bridge alternatives. In essence, the State of California's tolerance for risk should be the deciding factor in selecting an alternative. The results of this analysis provide the State's leadership with the information necessary to make that decision.

SENSITIVITY ANALYSIS

We conducted sensitivity analyses to test the robustness of the risk assessment, examining two scenarios.

Caltrans could choose to use the design-build approach for the alternatives requiring significant design. We tested this scenario and present the results in Table 4-3.

Table 4-3. Risk Assessment Results for Design-Build Procurement

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	3.2	4.1	5.2	5.4	5.4	2.8
Environmental	0.1	0.8	1.7	2.5	2.4	2.7
Management	2.9	6.8	5.6	5.6	5.6	4.3
Acceptance and expectations	1.1	3.0	9.6	12.8	16.2	15.7
Risk total[a]	7.3	14.7	22.1	26.4	29.6	25.5

[a] The columns may not add up properly due to rounding of individual risk issue values.

Compared with the risk assessment summary (Table 4-2), which used a design-bid-build procurement method, the risk increased slightly, but the relative ranking of the projects remained the same.

Because meeting the expectations of the public and gaining its acceptance pose significant risk for certain alternatives, we examined the scenario of eliminating this factor from consideration (Table 4-4). We selected this risk driver to test for sensitivity since it had the most significant effect on the outcome.

Table 4-4. Reduced Scores for Probability and Impact for Acceptance and Expectations

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	6.2	8.0	10.0	10.5	10.3	5.3
Environmental	0.2	1.5	3.2	4.8	4.7	5.2
Management	5.6	5.7	4.1	4.1	4.2	2.5
Acceptance and expectations	0.0	0.0	0.0	0.0	0.0	0.0
Risk total[a]	11.9	15.2	17.3	19.4	19.2	13.0

[a] The columns may not add up properly due to rounding of individual risk issue values.

After setting the acceptance and expectations score to zero, the overall ranking of the alternatives changed slightly. The SAS rebid alternative still maintained the lowest overall risk, while the skyway alternative moved to second lowest risk. The redesigned SAS bridge alternative and the cable-stayed bridge alternatives maintained their position relative to each other—each with slightly increased risk.

ACTIONS FOR CALTRANS CONSIDERATION

During the course of the study, the PRT identified several potential actions that Caltrans might consider to enhance the probability of successful project completion. They are as follows:

- Reconcile the significant differences (engineering, seismic, cost, schedule, construction sequencing) between existing analyses to improve comparison of the alternatives. The assumptions for each of the analyses need to be explicit and comparable across the analyses of the alternatives.
- Before resoliciting the SAS bid or issuing a new solicitation package, ensure legislative funding is consistent with current project cost (finance plan).
- Reestablish coordination with key stakeholders (resource and permitting agencies, critics, etc.). Selection of Alternatives 2, 3, 4, 5, or 6 will require engaging key stakeholders to varying degrees. A proactive marketing and education plan by Caltrans will enhance success for the project.
- To enhance the competition,
  - consider changing the bonding requirement and using comprehensive prequalification (and indemnification) as an alternative;
  - revitalize the marketing effort with potential bidders—using the results of the early November bidders conference, develop a plan of action to actively engage the community to increase critical input into the planning, design, and construction phases of the project; and
  - continue the use of a bid stipend for a selected number of top bidders.
- To improve management, cost, and schedule performance,
  - revisit the incorporation of comments received from previous value analysis studies, constructability reviews, and contractor outreaches to ensure all possible changes have been made;
  - establish independent constructability review teams during design and construction;
  - consider establishment of schedule analysis and methods analysis teams; and
  - establish a cost and schedule management system to help communicate information to key stakeholders.

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Appendix A
Peer Review Team

This appendix lists attendees of the PRT meeting in Federal Highway Administration California Division offices November 1–5, 2004.

CHAIRMAN

Gene Fong, P.E.
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Mr. Fong is the FHWA Division Administrator of the California Division in Sacramento, CA. He provides executive direction over the activities within the Division to effectively promote, implement, and administer the largest and most complex Federal-aid program in the Nation. His previous experience includes Director of Field Services-East and Division Administrator for Washington. As the Division Administrator, he directed a 26 member multi-level staff which provided technical and program guidance on the Federal-aid Highway Program to the Washington Department of Transportation, Metropolitan Planning Organizations, local agencies, and both Federal and State resource agencies. Mr. Fong joined the Federal Highway Administration in 1971 and has held the positions of Assistant Area Engineer and Area Engineer in Michigan, District Engineer in Arizona, and Assistant Division Administrator in New York. In addition, he was the Construction Engineer in the former Region 5 (Homewood, Illinois) and Region 9 (San Francisco, California) Offices. In the Headquarters Office, he spent several years in research (asphalt mixtures) and implementation (technology transfer in highway pavements). He received a Bachelor of Science Degree and a Master of Science Degree in Civil Engineering from San Jose State University. He completed graduate level courses at the University of Maryland in asphalt materials, highway pavements, and statistics as part of the FHWA Full-time Graduate Studies Program. He is a Registered Professional Engineer in the State of Michigan.

TEAM MEMBERS

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Ms. Bobb has worked for the Federal Highway Administration since 1983. She worked in the Kansas Division for three years as an Assistant Division Bridge Engineer and has been in the California Division since 1988 as both an Assistant Division Bridge Engineer and the Division Bridge Engineer. In January 2003, she assumed the duties of Project Oversight Manager for the San Francisco-Oakland Bay Bridge East Span Replacement Project, an FHWA-designated major/mega project. She has a Bachelor of Science Degree in Civil Engineering from the University of Nevada, Reno, and a Master of Science in Civil Engineering from the University of California, Davis. She is a registered Professional Engineer in the State of California.

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Ms. Bollman is a senior environmental specialist with the California Division of the FHWA. She has more than 30 years experience working with environmental issues at the federal level. Her responsibilities include environmental oversight of complex highway and bridge projects in Caltrans District 4.

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Mr. Crawford has 28 years of design, project management, and managerial oversight of bridge projects with the Nevada Department of Transportation. He has been involved in several major projects, including the reconstruction of the I-15/US-95 Interchange in Downtown Las Vegas, the Hoover Dam Bypass, and Galena Creek Bridge. These projects include significant environmental issues, conflicts with heavy traffic, public involvement, unique construction methods, difficult construction conditions, and complex design issues. The I-15/US-95 interchange in Downtown Las Vegas was reconstructed using precast segmental construction and received an Award of Excellence from PCA in 2000. The Hoover Dam Bypass includes a crossing of the Colorado River using an 1100-foot long cast-in-place concrete segmental arch. The Galena Creek Bridge is a 690-foot long cathedral arch bridge that is unique in its appearance, design, and method of construction.

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Mr. Dewar is currently Acting Chief Operating Officer in the FHWA California Division Office. His regular position is Director of Field Operations including design and construction activities for the Federal-Aid Highway Program in CA. He was previously Chief of Engineering Services including structures and other engineering specialties. He has previous experience as FHWA Division Bridge Engineer in Missouri for 5 years, working on several major bridge projects crossing the Missouri and Mississippi Rivers. He was also the Supervisory Structural Engineer in the New York Division for 8 years working on several suspension bridges and other major bridge projects. He received his B.S. in Civil Engineering from Worcester Polytechnic Institute, MA, and Master of Engineering from Rensselaer Polytechnic Institute, NY, in 1985.

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Mr. Dong is a Project Development Specialist in the Sacramento Division of the Federal Highway Administration. He has been with FHWA since 1970 and since 2003 he has been a North Region team leader/project development engineer with project development oversight responsibilities in northern California. Before that, Mr. Dong served for 17 years as a project development specialist in FHWA Headquarters, Office of Project Development, where he provided environmental oversight for FHWA activities in the Great Lakes and Midwest. He also participated in FHWA's environmental rulemaking activities and was active in environmental policy and training development and deployment. For 8 years, he was assigned to a Federal Lands Highways Office as a design squad leader and environmental specialist responsible for highway project design and specifications.

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Mr. Dwyer is project manager for the $685 million replacement of the Cooper River Bridges in Charleston, SC. This project includes South Carolina's largest single construction contract, a $531 million design-build delivery that includes a cable-stayed bridge, two interchanges, and almost 28 lane miles of roadway on new structure. This structure includes a lifeline seismic criteria as Charleston has a history of earthquakes, including one in 1886 of magnitude 7.3. Charles is a professional engineer in Florida and South Carolina, and has been with SCDOT since 1999.

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Mr. Lewis was named Project Director of the Central Artery/Tunnel Project in December 2000, responsible for day-to-day management of arguably the most ambitious, complex, technologically challenging, and politically charged public works project in American history. He is an eleven-year veteran of the Central Artery/Tunnel Project. Prior to his appointment as Project Director, he served as Deputy Project Director for Design and Engineering. Mr. Lewis came to the Artery Project from the Massachusetts Highway Department, where he managed road and bridge projects in Western Massachusetts. A civil engineer, he was educated at McGill University in Montreal and the University of Vermont.

M. Myint Lwin, P.E., S.E.
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Mr. Lwin is the director of the FHWA Office of Bridge Technology and is responsible to provide national guidance in the design and construction of major bridges and related structures, develop national bridge program and engineering policies, and support research and development to continually improve the quality and safety of bridges. He has held positions as a structural design engineer for the FHWA Resource Center at San Francisco, as a bridge and structures engineer in the Washington DOT Bridge & Structures Office. He is Secretary, AASHTO Highway Subcommittee on Bridges and Structures and a Life Member of the American Society of Civil Engineers. Mr. Lwin served as Chairman of two NCHRP committees (NCHRP Project 12-38 “Improved Design Specifications for Horizontally Curved Steel Girder Highway Bridges” and NCHRP Project 10-57 “Structural Safety Appraisal Guidelines for Suspension Bridge Cables”). additionally, he was a member of the NCHRP Project 18-12 “Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements.” He has numerous technical publications dealing with bridge design and performance.

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Dr. Moore joined LMI after 10 years in construction management with the Army Corps of Engineers. He has been involved in planning, financial management, and construction management of large construction projects in the United States and overseas. He served as the chief financial officer in the New York District for the Corps and has been a project and resident engineer on various construction projects. At LMI, he has led analyses of federal government construction costs and numerous studies addressing construction management, facilities management, information management, and resource allocation issues. He developed a method and computer model for analyzing the fiscal impacts of DoD base openings and realignments, as well as resource allocation and cost models for the Corps of Engineers. Dr. Moore is a registered professional engineer in the states of Virginia and Pennsylvania. He holds master's degrees in engineering and business administration and a doctorate in civil engineering.

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Mr. Gray has 29 years of experience in engineering and design, independent cost estimating, validations, and external assessments. His cost estimating, cost analysis, economic analysis, and risk assessment expertise is derived from a number of engineering and project management assignments in the private sector, as well as from management of over 50 independent cost estimates and validations for such DOE projects as Accelerator Production of Tritium, Tritium Extraction Facility, Waste Receiving and Processing Module (WRAP I), and High Level Waste Removal from Filled Waste Tanks. He has a B.S. in chemical engineering from Iowa State University, is a registered professional engineer in Colorado and Ohio, and is a member of the American Institute of Chemical Engineers, Society of Mining Engineers, and Colorado Hazardous Waste Management Society.

Appendix B
Risk Assessment Approach

Risk is the possibility of suffering loss or harm. It is a function of the probability of an event occurring and the impact if it does occur. LMI has developed an assessment method that addresses these two components of risk in a structured way that can be implemented quickly to compare the relative risk of different project alternatives. The approach begins with the development of a set of objectives or success metrics that describes the conditions that must be met for the project to be viewed as successful. Supporting this set of metrics, we create an analysis framework of risk drivers and associated issues. Risk drivers are the areas that have the greatest impact on the risk of a project not meeting its stated objectives. Risk drivers are supported by issues, which are the major activities that directly influence the amount of risk experienced by a project. The result is a hierarchical structure that cascades for the alternative being considered.

In this method, data collection and initial analysis focus on the issue level. Data collection is a combination of reviewing existing policies, plans, and management reports and interviewing key stakeholders for each process. An assessment team, consisting of experienced people who know the project and alternatives being examined, performs this effort. Ensuring the assessment team is composed of functional experts is critical to the reliability of the analysis because they collectively make key initial judgments. Our method consists of six steps.

In the first step, the team creates a matrix that describes the key objectives or success metrics. These metrics are the baseline against which risk judgments are made. Table B-1 shows these metrics for the SFOBB analysis.

In the second step, the team evaluates each issue within a risk driver and its characteristics to gauge (1) the probability of an event that would impede the project from meeting its goals, and (2) the impact should such an event occur (in the remainder of this discussion this condition will be referred to simply as an event). This judgment, P_{id}, is made within the context of a factor-probability matrix. Table B-2 shows the heuristics used for assigning a value to the probability, P_{id}, of an event occurring for an issue within a particular risk driver.

Third, the team assesses the degree of impact, I_{id}, should the event occur. This judgment is made within the context of a degree-of-impact matrix, which characterizes the severity of impact—critical, significant, or marginal—and provides guidelines for making the judgment by describing the condition that exists for that issue for each impact category. Table B-3 shows these guidelines.

Table B-1. SFOBB Key Objectives and Success Metrics

Objective	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
			Redesigned cable-stayed			
	Repackaged SAS	Redesigned SAS, concrete tower	Single tower, asymmetric	Single tower, symmetric	Two tower, symmetric	Extended skyway
Seismic lifeline reliability	High	High	High	High	High	High
Cost ($ billion)						
T.Y. Lin[a]	1.2–1.4	1.2–1.4	1.1–1.5	1.0–1.3	1.2–1.5	0.8–1.0
Bechtel	1.7–1.8	—	1.5–1.7	—	—	—
IRT	1.6–1.7	—	0.9–1.1	0.7–0.9	0.5–0.7	—
Schedule						
T.Y. Lin	2011	2012	2013	2013	2013	2012
IRT	—	—	2011	—	2010	—
Acceptance and expectations	Known	Partially known	Unknown	Unknown	Unknown	Unknown
Constructability and biddability	Difficult	Difficult	Moderate	Moderate	Moderate	Routine
Environmental risk	None	Minor	Minor to moderate	Moderate	Moderate	Moderate

[a] These costs include the costs required to modify the E2/T1 and W2 contracts.

Table B-2. Probability Assignment Heuristics

Rating	Description
1	Very likely that the desired outcome will be met
3	Likely that the desired outcome will be met
5	Equally likely that the desired outcome will or will not be met
7	Unlikely that the desired outcome will be met
9	Very unlikely that the desired outcome will be met

Table B-3. Severity of Impact

Severity of Impact	Rating	Guidelines
High	5	Will cause a major effort, time, or cost impact
Medium	3	Will cause a moderate effort, time or cost impact
Low	1	Will cause a minor effort, time or cost impact

The final analytical task to be performed at the issue level is determining the magnitude of risk. Risk magnitude is the product of probability and impact, which can be represented mathematically by

$$R_i = P_i \times I_i,$$

where *i* designates the issue and *I* is the impact rating.

The remaining two steps in this method involve calculating the risk at the risk driver level and then using that information to calculate the risk for the alternatives being evaluated. The risk magnitude for a risk driver could then be expressed as the summation of the risk magnitudes for all of the issues *I* within the risk driver, or

$$R_d = \sum_{1,\mathrm{I}} R_i.$$

This assumes that each attribute has the same effect on risk at the element level, which is typically not the case. A weighting is needed for each issue to reflect its influence on the total risk at the risk driver level. Determining the relative influence of each issue is by necessity somewhat subjective. There are no quantitative measures for how important each issue is to success at the risk driver level or, for that matter, at any level. Subject matter experts familiar with the project and its alternatives, however, can make expert judgments on the importance of an issue. Making such judgments between two issues can be done with reasonable consistency. Unfortunately, most risk drivers have more than two issues. Our experience has shown that it is difficult, if not impossible, to make relative judgments across a set of issues in a consistent and replicable manner without a guiding structure or process. The analytic hierarchy process (AHP) is a technique that meets this need.

AHP is a well-known and frequently applied mathematical technique used to determine the importance or influence of one factor relative to another. It compares each factor with each other factor pairwise to determine its relative importance. For example, issue 1 would be compared to issue 2, then to issue 3, and so on for the total set of issues. The results of these comparisons for all issues become inputs to a matrix. When compared with itself, each issue has equal importance. Diagonal elements of the matrix, therefore, always equal one, and the lower triangle elements of the matrix are the reciprocal of the upper triangle. Thus, pairwise comparisons are collected for only half of the matrix issues, excluding diagonal issues. By applying matrix algebra, the eigenvalue and right eigenvector can be calculated and used to both estimate the relative weight, W_{id}, for each issue and measure the consistency of the relative judgment. These weights are then applied to the risk magnitude for each issue. The risk magnitude at the risk driver level then becomes

$$R_d = \sum_{1,\mathrm{I}} R_{id} \times W_{id}.$$

The same technique is applied at the alternative level. Weights are developed for each risk driver using AHP, and the risk magnitudes at the alternative level become the summations of the weighted risk magnitudes from the lower level. For the risk magnitude at the alternative level, this becomes

$$R_a = \sum_{1,D} R_d \times W_d.$$

The output of this approach is a hierarchy of information, beginning at the issue level and culminating at the alternative level.

With these outputs, it is possible to quickly assess risk, both across and within alternatives. Within an alternative, the hierarchical structure makes it possible to drill down to see which risk driver or issues are driving the risk. At each level, the components driving the risk can be identified. Thus, multiple views of the risk profile are available, depending upon the needs and desires of the viewer.

Appendix C
Risk Analysis

This chapter describes the results of the risk analysis completed by the PRT. The first section details the analysis of each alternative. The second describes the risk analysis results, framed in terms of the risk drivers, for completing the project using a design-bid-build procurement strategy. The third describes the sensitivity analysis conducted.

Analysis of Each Alternative

The following sections present the results of the PRT's risk analysis for each alternative. These sections form the basis for the probability and impact scores we assigned to each issue and describe how they translate to a total risk score for the alternative.

Alternative 1

Risk Matrix

Table C-1 shows the results of the PRT risk assessments for Alternative 1.

Table C-1. Risk Matrix for Alternative 1

Issue	Score	Observations
Technical, cost, and schedule	3.2	Limited cost risk at revised budget
Environmental	0.1	Limited risk of impact
Management	2.9	Some impact due to limited number of bidders with SAS experience
Acceptance and expectations	1.1	Limited impact

For technical, cost, and schedule, the SAS alternative had limited risk when the revised budget was considered. The PRT reviewed and assessed 6 different technical issues, 11 cost issues, and 2 schedule issues. In most cases, the SAS design had equal or lower risk than the other alternatives. The exceptions are in technological innovation, schedule delays, and post award cost growth.

Technical, cost, and schedule impacts are rated mostly medium to high, reflecting our assessment that most issues, if realized, will significantly impact cost, schedule, safety, or quality. The only impacts rated low relate to coordination, concurrent construction with other projects, design delays, and termination of existing contracts.

Environmental issues pose very limited risk to successful project completion.

Management poses some risk to successful project completion due to the limited number of potential bidders with SAS experience and the fact that Caltrans has not previously designed and built an SAS bridge.

TECHNICAL, COST, AND SCHEDULE

Technical Risks

The SAS is ahead of the other alternatives in many areas, particularly design status, political, and environmental hurdles. Selection of this alternative obviates redesign and minimizes changes to existing or planned structures. Existing construction contracts will not be affected. Furthermore, the SAS has the least impact on other SFOBB projects (for example, the existing skyway) because other projects have been designed around the SAS concept. Site conditions are fully known and characterized for this alternative; thus, the likelihood of encountering different site conditions is very low. Of particular significance, the SAS currently meets seismic lifeline performance criteria, and peer review is complete.

Cost Risks

The issue of cost is uncertain. One contractor bid was received, which provides a very limited measure of confidence: one bid does not establish market value. The $1.4 billion bid may reflect the upper limit of expected future bids, largely due to the material price volatility and the significant bonding costs due to the size of the contract and the risks that the contractor was required to assume. Because the bid is in-hand and conservative, the likelihood that it contains cost-estimating errors or omissions, items that raise the price, is lower.

Although the SAS is particularly vulnerable to the price of steel, which has increased over the past year, future volatility is likely to decrease as new or existing production capacity meets demand. Thus, we assign a medium rating to both probability and impact for material prices.

Construction risks pertain to the availability and qualifications of the labor pool, availability of construction equipment due to other ongoing projects, contractor delays, and general complexity of construction. The SAS is slightly more risky than other alternatives, primarily due to the complex construction of the steel superstructure, coupled with the need for specialized labor.

Post-award cost growth (such as change orders and claims) is likely for the SAS because of the size and complexity of the project relative to other alternatives. Although the probability is slightly greater, the cost impact is considered equal to other alternatives.

Schedule Risks

Schedule delays due to construction are likely to occur due to the complex nature of construction, coupled with the lack of contractor experience with the SAS design.

ENVIRONMENTAL

Alternative 1 carries the lowest environmental risk to successful project completion. All permits are currently approved and coordinated for the steel SAS design. The SAS is almost environmentally risk-free (a risk score of 1) when viewed separately. The interrelationship of environmental risk with acceptance and expectation risk is apparent when the two scores are compared. Much of the acceptance and expectation risk is tied to the permits and approvals from environmental agencies.

MANAGEMENT

Caltrans has the management acumen to handle large, complex design-bid-build projects successfully, regardless of the alternative chosen. It has demonstrated that is capable of adapting to needed organizational and management changes to improve cost and schedule performance. However, Caltrans does not have experience on which to rely when dealing with the technically complex SAS design and construction techniques. Also, the industry experience is limited in that no SAS bridges have been designed and built in the United States in the last 65 years.

The risk of modification to existing contracts is very low since the SAS was originally designed to work with the existing contracts. Payment and performance bonds can be obtained for the SAS, but may cost as much as 25 percent of the contract amount even if the bond is written for some lower amount. Caltrans is likely to obtain an adequate number of bidders if it continues and enhances its active contractor outreach and marketing efforts, and makes appropriate changes to the bid package.

ACCEPTANCE AND EXPECTATIONS

Additional public input is not needed in that the SAS design remains the same and was already approved through the public process. Public expectations are likely to be met. At issue is the impact of additional taxes and whether funding needs to be made at the state or regional level. The general public expectations of aesthetics and cost-effectiveness are likely to be met.

Summary

Though the SAS concept is complex and likely more expensive than the alternatives, its overall state of design and development is more advanced. It also represents minimal impact to other Bay Bridge projects and has cleared the political and environmental hurdles. These factors all result in generally lower risk than that of the other alternatives.

Alternative 2

Risk Matrix

Table C-2 shows the results of the PRT risk assessments for Alternative 2.

Table C-2. Risk Matrix for Alternative 2

Issue	Score	Observations
Technical, cost, and schedule	4.1	Limited technical concerns
Environmental	0.8	Likely impact, but low relative effect
Management	3.0	Some impact due to limited number of bidders with SAS experience
Acceptance and expectations	3.0	Limited impact

Alternative 2 has more risk than Alternative 1. Technical, cost, and schedule for the SAS concrete-tower concept is slightly less risky and complex than the SAS steel tower, and construction risks are commensurate with the degree of complexity. The concrete design is less susceptible to the volatility of materials because of its low reliance on steel. However, the concrete-tower concept will require redesign, particularly the T1 foundation, and therefore has geological and environmental permitting implications.

The cost impacts associated with Alternative 2 are similar to Alternative 1, which the risk matrix reflects. The only difference is in the cost impact related to termination or modification of existing contracts. Alternative 1 has no impact on existing contracts, but Alternative 2 necessitates a change to the E2 and T1 contracts, which would incur some costs.

As in Alternative 1, environmental issues pose low risk to successful completion.

Management issues pose risk, as in Alternative 1, to successful project completion due to the limited number of potential bidders with SAS experience and the fact that Caltrans has not designed and built an SAS bridge.

TECHNICAL, COST, AND SCHEDULE

Technical Risks

The engineering metrics for the concrete-tower SAS design are unavailable, making the likelihood of design scope changes slightly higher than for the steel SAS. Countering this is the slightly lower risk probability for material availability, since the concrete SAS relies less on the huge steel quantities that characterize Alternative 1. The design status is more risky for Alternative 2 since the tower is not designed. The likelihood of interface problems with other projects is slightly higher for Alternative 2, mainly due to the redesign of T1 and the main cable, but is still ranked low. The concrete tower is more known from a technological standpoint and less likely to experience changes in fabrication and construction tolerances than a steel tower.

Finally, a change to a concrete tower requires new seismic performance guidelines. New shear links will need to be tested. Thus, the risk matrix reflects a higher likelihood of technical problems related to seismic lifeline performance.

Cost Risks

All alternatives except Alternative 1 are likely to experience cost changes due to technical, environmental, political, and management issues. This is because Alternative 1 is the accepted design and has largely overcome these issues. For Alternative 2, several technical issues may affect the project, including additional research and testing, and foundation redesign. The likelihood of cost-estimating errors and omissions is slightly higher for Alternative 2 because the design is not complete; however, the increase is not significant over Alternative 1.

Design scope changes are more likely for the concrete SAS, particularly in regard to the T1 foundation. The design scope is not as well defined as for the steel SAS. As previously discussed, selection of Alternative 2 may require termination of the T1 contract, so both the likelihood and impact are greater than for Alternative 1.

Both the construction and post award cost growth risks are slightly lower for the concrete SAS design. The concrete tower is more standard within the industry, and the need for specialized equipment is reduced somewhat from the steel SAS. The risk of scheduling conflicts with other large construction contracts, either domestically or globally, is slightly higher for Alternative 2.

Schedule Risks

In terms of schedule risks, Alternative 2 has a higher risk of design delays than Alternative 1, primarily due to tower and E2 and T1 foundation redesign. However, construction delays are less likely for Alternative 2 because the construction is less complex.

Environmental

Environmental risk increases from that of the steel SAS, mostly because additional scope is required for Pier T1 and W2. The environmental impact statement (EIS) was sufficiently broad in its description that a supplement would not be required, and a revised record of decision (ROD) is the worst-case scenario for the additional impact of the alternative. Additional public involvement is expected, but with minimal impact because the alternative was primarily a materials change and not a major form change. Permit modifications are likely to be by letter and not a reissue. The larger foundations have an impact but should not compromise expectations.

Management

As in Alternative 1, Caltrans has the management acumen to handle large, complex design-bid-build projects successfully, regardless of the alternative chosen. It has demonstrated that it is capable of adapting to needed organizational and management changes to improve cost and schedule performance. However, Caltrans does not have experience on which to rely when dealing with the technically complex SAS design and construction techniques. Also, the industry experience is limited in that no SAS bridges have been designed and built in the United States in the last 65 years.

The risk of modifications to contracts is moderate since the SAS was originally designed to work with the existing contracts. Payment and performance bonds can be obtained for the SAS, but may cost as much as 25 percent of the contract amount even if the bond is written for some lower amount. Caltrans is likely to obtaining an adequate number of bidders if it continues and enhances its active contractor outreach and marketing effort.

Acceptance and Expectations

The need for additional public input is limited in that the SAS design remains essentially the same and is already approved through the public process. Of specific interest would be the scope increase for Piers T1 and W2 and a slightly increased risk of not successfully meeting project cost and schedule goals. Public expectations are likely to be met. At issue is the impact of additional taxes and whether funding needs to be made at the state or regional level. The general public expectations of aesthetics and cost-effectiveness are likely to be met.

Summary

The concrete SAS has slightly more overall risk than the steel SAS. In general, the probability of an unsuccessful project is higher for the concrete tower than the steel SAS, but the cost impacts are similar. Although the concrete tower concept is less complex from a technical standpoint, and less susceptible to the cost impacts from volatile steel prices, it does require redesign of the tower and foundation. This may entail additional research and testing. The costs for the concrete SAS are also more susceptible to other risks, such as environment and public acceptance. Finally, a change to a concrete SAS may require new seismic performance guidelines.

Alternative 3

Risk Matrix

Table C-3 shows the results of the PRT risk assessments for Alternative 3.

Table C-3. Risk Matrix for Alternative 3

Issue	Score	Observations
Technical, cost, and schedule	5.2	Limited technical concerns, schedule risk driven by expectations
Environmental	1.7	Likely impact, but low relative effect
Management	2.1	Limited impact
Acceptance and expectations	9.6	Potential public reaction to change in aesthetics high

The redesigned single-tower, asymmetric, cable-stayed bridge with an open composite section bridge deck poses more risk than the two SAS alternatives. The technical risks are higher because of the uncertain scope definition, incomplete design, and technical interface with other SFOBB projects. The cost impact is related to the termination or modification of existing contracts. Whereas Alternative 1 has no impact on existing contracts, selection of Alternative 3 necessitates termination of the T1/E2 contract and modification of the skyway contract, which would incur costs.

Since the bridge design differs from that of the approved SAS alternatives, a correspondingly higher level of risk is associated with public acceptance and meeting the expectations of citizens in the Bay Area.

Technical, Cost, and Schedule

Technical Risks

The scope definition for this alternative is moderately risky. The hinge location may change and will cause interference with the skyway. Also, this alternative may require redesign of the W2, T1, and E2 foundations. The asymmetric span is also more difficult to design; thus, the risk is fairly high for both design status and interface with other projects. Material availability has about the same risk as for the concrete SAS.

The risk associated with technological innovation is about the same as for the concrete SAS. An asymmetric design carries more risk than a balanced cable-stayed (Alternatives 4 and 5) design and is new to Caltrans. The risk for seismic lifeline requirements is higher for Alternative 3 than for either of the SAS options. The mass of the cable-stayed is much greater than for the SAS. The conceptual stage of this design will likely extend the design process. These structures will have an unknown impact on the adjacent approaches, which must be thoroughly addressed to maintain the lifeline status of this crossing.

Cost Risks

Technical issues which impact costs include long frames, additional frames, additional wind tunnel testing, and redesign of foundations. The W2 foundation needs to be strengthened. The cable-stayed design also has cost implications related to legislative, environmental, and public acceptance issues because it is a departure from the SAS. Related to cost-estimating uncertainty, information is very limited and based on only very preliminary design. The two estimates presented to the PRT vary greatly, thus they are unlikely to be sound, complete, and error-free.

Material and labor costs are not much of a risk for the cable-stayed design. However, changes to design scope are more likely than for the SAS options because the scope has not been established or approved. The design is less than 5 percent complete. Coordination issues are not likely for the cable-stayed design because the structure type is better known to designers and constructors. For the same reason, overall construction problems and post award cost growth are less likely than with the SAS. Specialized equipment is still required for cable-stayed construction, but it is commonly available. The construction process is less complex.

The asymmetric cable-stayed design will require modification or termination of the T1/E2 foundation contracts and modification of the skyway contract. The cost impact of this alternative is higher than that of the SAS alternatives.

Schedule Risks

Design delays are more likely for the asymmetric cable-stayed design because the scope is not well defined, and it has the least amount of design completion of any alternative. However, the risk for construction delays is less than for the SAS because cable-stayed bridge construction is more prevalent in the industry. Schedule impact increases are due to environmental permitting and reviews.

ENVIRONMENTAL

This alternative is a major change to the structure of the bridge, and an environmental supplement, though probably not required under National Environmental Policy Act (NEPA), may be desirable due to the higher tower and larger tower foundation. A new ROD is likely to be required, but it should not be a difficult process because the change from the steel SAS to a similar-size cable-stayed bridge is not as extensive as for the other alternatives. Public involvement would be sought if a supplement is done. The increased level of change in the in-water work would cause all associated permits to be reviewed and may require a few revisions to permits and additional consultation. Changes to the on-shore foundations at pier W2 will likely involve agencies and organizations responsible for oversight of historical and archeological issues. None of the risks appear insurmountable; however, they could result in schedule impacts.

MANAGEMENT

The risk associated with contractor competencies and capabilities are low for cable-stayed bridges since the industry has adequate experience in dealing with these types of structures. As with Alternative 2, this design will require changes to the ongoing projects since foundations T1 and W2 need to be redesigned. This poses moderate risk and potentially generates cost increases and schedule delays. Unlike Alternatives 1 and 2, an adequate number of bidders on the contract is expected.

ACCEPTANCE AND EXPECTATIONS

Since the bridge structure significantly differs from the one the public approved under Alternative 1, public input will be required and cost and schedule impacts could occur, thereby posing moderate risk to project success.

SUMMARY

Considering all factors, the asymmetric cable-stayed design is more risky than the SAS alternatives. Although the impacts are similar to those of the SAS, the likelihood of undesirable events occurring is higher. This is primarily due to the uncertainty of the design and likelihood of scope changes. Selection of this alternative is also more detrimental to existing work and contracts, and interface problems are anticipated. Seismic lifeline requirements are more sensitive with this option. Technical, environmental, and political factors are highly likely to affect the costs.

The cable-stayed design is less risky than the SAS in the areas of construction, post award cost growth, and overall likelihood of schedule delays in the construction phase. This is due to the less complex nature of cable-stayed bridges and more familiarity within the industry with this type of construction.

Alternative 4

Risk Matrix

Table C-4 shows the results of the PRT risk assessments for Alternative 4.

Table C-4. Risk Matrix for Alternative 4

Issue	Score	Observations
Technical, cost, and schedule	5.4	Limited technical concerns, schedule risk driven by expectations
Environmental	2.5	Likely impact, but low relative effect
Management	2.1	Limited impact of potential contract modifications
Acceptance and expectations	12.8	Potential public reaction to change in aesthetics high

The risk for the redesigned single-tower, symmetric, cable-stayed bridge is very similar to Alternative 3 for most issues. For this reason, we address only the differences.

Technical, Cost, and Schedule

Technical Risks

The scope definition is moderately risky for this alternative. The scope is less well defined than that of the asymmetric cable-stayed design. In addition to changing hinge location and redesign of foundations, an additional pier is required for the symmetric cable-stayed. Soil borings are not available for this new pier. Also, issues related to the short span and uncertainty with the Coast Guard permit relating to navigation interests because of the narrower channel are considerations.

Material availability is not as much of a risk for Alternative 4 since regular concrete would be used. Materials, in general, are not a significant impediment. Similar to the asymmetric cable-stayed alternative, this one has little or no design development to support it, but because it is an easier overall design than the asymmetric, it has a slightly lower risk for design. The risk is still high, indicating the likelihood that design status will affect the project.

This option will likely encounter interface problems with the skyway, but to a lesser degree than the asymmetric design. Technological innovation is also slightly less likely to impact the project because of the symmetric design and a larger pool of experienced contractors. However, this is still a new structure type for Caltrans.

Cost Risks

With regard to cost considerations, the symmetric cable-stayed design is about equivalent to the asymmetric design. Alternative 4 does require a new deep-water pier. Only one very preliminary cost estimate has been prepared for this alternative; thus, cost-estimating errors are highly likely and material quantity and pricing are uncertain. The new pier location results in more site investigation, thus the higher probability that unknown site conditions can impact the project costs.

Schedule Risks

Other cost and schedule issues are the same for this option as for the asymmetric cable-stayed design.

Environmental

For Alternative 4, the NEPA considerations increase, primarily because of the requirement for a new pier in the bay. As with Alternative 3, an environmental supplement may be desired, if for no other reason than to document the controversy of installing another pier. Public involvement is expected to be required. Litigation risk is elevated because of the resulting narrowing of the channel and the risk of the public expectations not being met with regard to bridge form. The Port of Oakland may raise concerns about impacts to its port expansion plans due to the narrower clear span over the channel. The Coast Guard will need to get involved to revise the bridge permit. Biological opinions may need to be revised because of the additional pile driving and marine work. The BCDC and MTC design review and engineering criteria review boards may be involved since the structure is taking on a new, less dramatic shape, and the signature nature of the project is being changed.

Management

This alternative has the same management risks as Alternative 3.

Acceptance and Expectations

The symmetric design of the bridge is likely to trigger more involved public input and a corresponding likelihood that the schedule may slip due to its involvement. Advocacy groups could feel that their previously negotiated concerns and expectations are not being met, thereby increasing risk in this area.

Summary

The redesigned single-tower, symmetric, cable-stayed bridge has a risk similar to that of Alternative 3. The scope is less well defined, primarily due to the new pier location, shorter span, and shipping uncertainties due to the narrower channel. However, the material availability, ease of overall design, and interface problems are slightly less risky for this option than for the asymmetric design. Cost impacts for the symmetric design do not significantly differ from those for the asymmetric design.

The increased risk relative to Alternative 3 results from the increased environmental risk associated with additional permitting requirements and the increased public expectation risk associated with the changed design.

Alternative 5

Risk Matrix

Table C-5 shows the results of the PRT risk assessments for Alternative 5.

Table C-5. Risk Matrix for Alternative 5

Issue	Score	Observations
Technical, cost, and schedule	5.4	Limited technical concerns, schedule risk driven by expectations
Environmental	2.4	Likely impact, but low relative effect
Management	2.2	Limited impact
Acceptance and expectations	16.2	Potential public reaction to change in aesthetics high

The risk for the redesigned, two-tower, cable-stayed bridge (Alternative 5) is very similar to that of the other cable-stayed options. For this reason, we address only the differences.

Technical, Cost, and Schedule

Technical Risks

The scope risk is in the moderate range, slightly lower than the risk for Alternative 4. Soil borings are again an issue, but less so for this option because the borings avoid deep water. The two-tower, cable-stayed bridge would require redrilling for geotechnical investigation for the E2 foundation at a new location. Wind tunnel testing may also be required.

Material availability risk is low for this alternative, the same as for Alternative 4. Regular concrete can be used, which is readily available. The risk associated with design status is fairly high because no design exists. Interface problems with the two-tower design are judged as risky as those for Alternative 3 (the asymmetric, single-tower, cable-stayed bridge). The hinge relocation causes interference with the skyway and will require the redesign of W2, T1, and E2 foundations. Risks due to technological innovation are low because of the symmetric design and a larger pool of experienced contractors.

Seismic lifeline requirements are equal in probability between this alternative and Alternatives 3 and 4. As stated earlier, the conceptual stage of this design is very likely to extend the design process. These structures will have an unknown impact on the adjacent approaches, which must be thoroughly addressed to maintain the lifeline status of this crossing.

Cost and Schedule Risks

The two-tower, symmetric, cable-stayed design has cost risks similar to those of the other two cable-stayed alternatives. Alternative 5 has significant risk sensitivity to technical issues because significant changes will be required to the foundations currently under construction or already completed. Foundation E2 will be relocated, T1 is scrapped, and W2 needs to be modified.

Other cost risks and impacts are identical to the ratings assigned to the other cable-stayed alternatives. The exceptions are the potential for cost-estimating errors and termination of existing contracts, which are both likely. Substantial cost consequences are envisioned for most risks. Cost impacts are also expected from inadequate coordination, concurrent construction, and schedule delays due to design changes.

ENVIRONMENTAL

Alternative 5 is a dramatic visual change from the steel SAS bridge design. That being the case, an environmental supplement, though probably not required by NEPA, may be desired. A new ROD will be required. The risk of litigation is also elevated because of the new look. The Coast Guard will be involved because the bridge piers would move and the channel alignment would move slightly. If the revised channel alignment causes navigation challenges or restricts shipping, the Port of Oakland will likely get involved, but this risk is low and litigation risk is actually less for this alternative than for Alternatives 4 or 6. The Bay Conservation and Development Commission (BCDC) will likely be heavily involved because of the new look. This alternative would require additional work on Yerba Buena Island; therefore, the Section 106 process would possibly need to be revisited.

MANAGEMENT

The management risks are the same as in Alternatives 3 and 4, except for the impact of modifying existing contracts.

ACCEPTANCE AND EXPECTATIONS

Public involvement risk will be significant because of the new look the twin spans bring to the structure. This will generate increased public involvement, with a sense that public trust was not maintained and initial public expectations were not met. Increased interest by advocacy groups could pose potential risk to both cost and schedule.

SUMMARY

The risk is nearly identical for the redesigned, two-tower, cable-stayed bridge (Alternative 5) as for the other cable-stayed options. This option is not designed, requires new soil borings, and impacts the foundation work at E2, T1, and W2. Thus, the technical risks associated with scope definition, design status, and project interface are likely to occur. The environmental and public acceptance and expectation risks are increased relative to other cable-stayed alternatives.

Alternative 6

RISK MATRIX

Table C-6 shows the results of the PRT risk assessments for Alternative 6.

Table C-6. Risk Matrix for Alternative 6

Issue	Score	Observations
Technical, cost, and schedule	2.8	Limited technical concerns, schedule risk driven by expectations
Environmental	2.7	Likely impact, but low relative effect
Management	1.3	Limited impact
Acceptance and expectations	15.7	Potential public reaction to change in aesthetics high

Alternative 6 has lower technical, cost, schedule, and management risk than Alternatives 2 through 5. The skyway is an extension of existing work, which is well known. Furthermore, the design is the simplest of all the alternatives. The cost and technical impacts are less than those for the other alternatives, the risk to project cost and schedule goals is low. Environmental risks are similar to those of the cable-stayed bridge Alternatives 4 and 5. Acceptance and expectation risk is less than Alternatives 4 and 5, but higher than the SAS alternatives.

TECHNICAL, COST, AND SCHEDULE

Technical Risks

The scope definition risk is higher for the skyway than for the SAS with steel tower, because the scope is fully defined for the SAS. However, the scope risk rating is lower for the skyway than all other alternatives because of its simplicity. The skyway superstructure is less problematic, but adding a new foundation in the deep channel poses major uncertainty. These considerations are reflected in a similar relative risk ranking for the design status. Material availability is the least risky of all the alternatives. The skyway uses very common, standard materials. Risk of interface problems with other SFOBB projects is rated moderate for the skyway. This alternative will require termination of the T1 and E2 foundation contracts, as well as verifying the capacity of the W2 foundation. The likelihood of a significant technical impact is higher than that of the SAS alternatives, but less than the cable-stayed alternatives.

Technological innovation problems are not likely to occur for the skyway. It is a very familiar structure. Likewise, seismic lifeline requirements pose minimal risk. The extension of the skyway can be completed using the established requirements from the approach structure.

Cost Risks

The skyway has moderate cost sensitivity to technical, environmental, political, and management issues. It has higher likelihood than the known SAS project, but lower likelihood than the other alternatives. The new deep-water pier adds cost risk due to technical requirements, and some risk stems from environmental issues. Coast Guard concerns with the skyway represent another unknown that could impact costs.

The potential for cost-estimating errors is fairly low for the skyway. Costs for this alternative can be more accurately estimated from the existing skyway contract. In addition, several bids were received on the skyway.

The skyway is least likely to experience changes in material and labor pricing. Materials are very common. The skyway is not likely to result in design scope changes that could affect costs. It is a continuation of the existing skyway design, but with longer spans. The likelihood of design changes is considered equivalent to the risk associated with the concrete-tower SAS design.

Similar to some of the cable-stayed designs, the skyway is ranked moderate in risk for changing site conditions that could affect costs. New pier locations or size mean more site investigation.

Coordination problems are minimal for the skyway. The construction is standard and merely extends existing work. Likewise, construction risks and cost growth after award have low probability. This option is straightforward construction, and specialized equipment exists on-site. Furthermore, construction techniques are well known, and capable, experienced contractors are available.

Schedule Risks

Schedule delays due to design are unlikely for the skyway. This alternative can borrow from the design of the approach skyway. Design delays are lower in probability than for all other alternatives except the steel SAS. More significant, the skyway is least likely to result in construction delays. The skyway design is most common and carries the least risk.

ENVIRONMENTAL

Alternative 6 is the most dramatic change from the steel SAS design. A supplemental environmental document may be a wise option should this alternative be chosen. A new NEPA ROD would be required. Public expectations for a signature bridge would not be met, and the risk of litigation is therefore higher. Channel width is reduced, which may impact the Port of Oakland expansion. The Coast Guard is likely to require a new bridge permit. Other permit impacts would be similar to Alternative 4 as additional piers are required.

MANAGEMENT

Management risk for this alternative is the lowest of all six alternatives, due primarily to the fact that Caltrans is currently building the skyway (hence, learning curve issues are reduced and a smooth construction management process is in place), more than three bidders are likely for this alternative, and the risk associated with bonding could be lower if multiple contracts of lesser value were used.

ACCEPTANCE AND EXPECTATIONS

This alternative poses some risk for acceptance and expectations, compared with the SAS alternatives, since it does not have the signature bridge design desired by the public and advocacy groups.

SUMMARY

The skyway generally has lower technical, cost, and schedule risk than all other alternatives. Most technical risks are lower for the skyway than for the steel SAS. The skyway represents a simpler, more common structure, less hampered by material price volatility. The skyway presents the least potential problems due to design and construction delays.

These low risks are offset somewhat by environmental and acceptance and expectation risks.

RISK ANALYSIS

The PRT calculated the relative weights of the risk drivers. Using AHP, the risk drivers were assigned the following relative weightings:

- Technical, cost, and schedule risk = 0.255
- Environmental risk = 0.078
- Management risk = 0.187
- Acceptance and expectation risk = 0.481.

Final Weighted Values

Table C-7 summarizes our results, assuming a design-bid-build procurement strategy.

Table C-7. Summary of Risk Assessment Results

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	3.2	4.1	5.2	5.4	5.4	2.8
Environmental	0.1	0.8	1.7	2.5	2.4	2.7
Management	2.9	3.0	2.1	2.1	2.2	1.3
Acceptance and expectations	1.1	3.0	9.6	12.8	16.2	15.7
Risk total[a]	7.3	10.8	18.6	22.9	26.2	22.5

[a] The columns may not add up properly due to rounding of individual risk issue values.

The following subsections show the data for each of the risk issues.

Technical, Cost, and Schedule Risk Issues

Technical, Cost, & Schedule Risk	Weight	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5		Alt 6			Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
		P	I	P	I	P	I	P	I	P	I	P	I							
Technical (43.5%)																				
Scope definition for each alternative	0.08	1	5	2	5	5	5	7	5	6	5	4	5		0.41	0.82	2.05	2.87	2.46	1.64
Material availability (quantity, quality, schedule)	0.03	3	5	2	5	3	5	2	5	2	5	1	5		0.45	0.30	0.45	0.30	0.30	0.15
Design status	0.02	1	5	3	5	8	5	7	5	7	5	4	5		0.12	0.35	0.92	0.81	0.81	0.46
Interface with other project systems	0.04	1	3	2	3	7	3	6	3	7	3	4	3		0.11	0.22	0.76	0.65	0.76	0.43
Technological innovation	0.01	5	3	4	3	4	3	3	3	3	3	1	3		0.14	0.11	0.11	0.08	0.08	0.03
Seismic lifeline requirements	0.26	1	5	3	5	4	5	4	5	4	5	1	5		1.28	3.83	5.10	5.10	5.10	1.28
														Total Technical	**2.49**	**5.61**	**9.38**	**9.80**	**9.50**	**3.98**
Cost (36.1%)																				
Cost Sensitivity to schedule, tech, envir, political, and management risk	0.06	1	5	6	5	8	5	8	5	8	5	4	5		0.30	1.77	2.36	2.36	2.36	1.18
Inadequate coordination	0.02	5	1	4	1	3	1	3	1	3	1	1	1		0.10	0.08	0.06	0.06	0.06	0.02
Concurrent construction within project	0.02	3	1	3	1	3	1	3	1	3	1	3	1		0.05	0.05	0.05	0.05	0.05	0.05
Concurrent construction outside project	0.01	2	3	3	3	4	3	4	3	4	3	4	3		0.04	0.05	0.07	0.07	0.07	0.07
Construction risks	0.08	5	4	4	4	3	4	3	4	3	4	2	4		1.66	1.33	1.00	1.00	1.00	0.66
Cost impacts due to termination/modification of existing contracts	0.01	1	1	9	2	9	5	9	5	9	5	9	4		0.01	0.25	0.63	0.63	0.63	0.50
Potential for cost estimating errors and variations	0.01	2	**3**	3	**3**	7	**3**	8	**3**	7	**3**	3	**3**		0.04	0.05	0.13	0.14	0.13	0.05
Changes in material and labor costs	0.01	5	5	4	5	3	5	3	5	3	5	2	5		0.33	0.26	0.20	0.20	0.20	0.13
Design scope changes impact on cost	0.08	1	5	3	5	5	5	5	5	5	5	3	5		0.42	1.26	2.10	2.10	2.10	1.26
Potential for changed conditions	0.03	1	5	2	5	2	5	5	5	5	5	5	5		0.17	0.34	0.34	0.85	0.85	0.85
Post award cost growth - change orders, claims	0.03	7	5	5	5	3	5	3	5	3	5	2	5		0.88	0.63	0.38	0.38	0.38	0.25
														Total Cost	**3.98**	**6.07**	**7.31**	**7.83**	**7.82**	**5.04**
Schedule (20.4%)																				
Schedule delay - design	0.03	1	2	3	2	4	2	4	2	4	2	2	2		0.06	0.17	0.23	0.23	0.23	0.12
Schedule delay - construction	0.18	7	5	5	5	4	5	4	5	4	5	2	5		6.13	4.38	3.50	3.50	3.50	1.75
														Total Schedule	**6.18**	**4.55**	**3.73**	**3.73**	**3.73**	**1.87**
														Total Technical, Cost, Schedule	12.66	16.24	20.42	21.37	21.05	10.89

Environmental Risk Issues

Environmental Risk Issues	Weight	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5		Alt 6			Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
		P	I	P	I	P	I	P	I	P	I	P	I							
NEPA reevaluation required/desired	0.024	1	1	9	1	9	2	9	3	9	3	9	3		0.02	0.22	0.43	0.65	0.65	0.65
Supplement required/desired	0.166	1	1	1	3	5	4	6	5	7	5	7	5		0.17	0.50	3.32	4.98	5.81	5.81
New/revised ROD	0.063	1	1	9	1	9	2	9	2	9	2	9	2		0.06	0.57	1.13	1.13	1.13	1.13
Public involvement required/desired	0.117	1	1	3	1	5	4	9	5	9	5	9	5		0.12	0.35	2.34	5.27	5.27	5.27
Risk of environmental related litigation	0.303	1	1	1	4	5	4	6	5	6	4	7	5		0.30	1.21	6.06	9.09	7.27	10.61
Impact on dredging and fill permits (USACE 404/10, BCDC, DMMO, RWQCB-401)	0.055	1	1	9	3	9	4	9	5	9	5	9	5		0.06	1.49	1.98	2.48	2.48	2.48
Impact to BCDC permits and approvals	0.068	1	1	9	3	9	4	9	5	9	5	9	5		0.07	1.84	2.45	3.06	3.06	3.06
Section 106	0.009	1	1	1	1	7	4	1	1	7	3	1	1		0.01	0.01	0.25	0.01	0.19	0.01
Impact on USFWS Biological opinion	0.061	1	1	5	3	5	3	5	3	5	3	5	3		0.06	0.92	0.92	0.92	0.92	0.92
Impact on NOAA Fisheries Biological opinion	0.096	1	1	5	4	5	4	7	5	7	5	7	5		0.10	1.92	1.92	3.36	3.36	3.36
Impact on CA Dept of Fish and Game permits	0.007	1	1	3	2	3	2	3	2	3	2	3	2		0.01	0.04	0.04	0.04	0.04	0.04
Impact USCG bridge permit	0.037	1	1	9	2	9	2	9	4	9	4	9	4		0.04	0.67	0.67	1.33	1.33	1.33
														Total	1.01	9.72	21.51	32.31	31.50	34.66

Management Risk Issues

Management Risk Issues	Weight	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5		Alt 6			Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
		P	I	P	I	P	I	P	I	P	I	P	I							
CALTRANS (for Design-Bid-Build) has the required organizational and business competencies/skills, capabilities, and availability to manage the project	0.06	1	5	1	5	1	5	1	5	1	5	1	5		0.30	0.30	0.30	0.30	0.30	0.30
Industry (for Design-Bid-Build) has the competencies/skills, capabilities, and availability required to manage the project	0.06	1	5	1	5	1	5	1	5	1	5	1	5		0.32	0.32	0.32	0.32	0.32	0.32
Modifications are not necessary to existing contracts for each option	0.03	1	1	9	2	9	4	9	4	9	5	9	3		0.03	0.54	1.08	1.08	1.35	0.81
3 (or more) bidders can be obtained for the project option	0.42	3	5	3	5	2	4	2	4	2	4	1	3		6.35	6.35	3.38	3.38	3.38	1.27
Obtaining payment and performance bonds for each project option	0.42	4	5	4	5	3	5	3	5	3	5	2	5		8.46	8.46	6.35	6.35	6.35	4.23
	1.00													Totals	15.45	15.96	11.42	11.42	11.69	6.92

Acceptance and Expectations Risk Issues

Acceptance and Expectation Risk Issues	Weight	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5		Alt 6			Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
		P	I	P	I	P	I	P	I	P	I	P	I							
Public (e.g., special interest groups) input is not required	0.08	1	2	2	3	5	5	6	5	7	5	7	5		0.16	0.47	1.95	2.34	2.73	2.73
Public (e.g., special interest groups) input will not extend the project option schedule	0.42	1	2	2	3	5	5	6	5	7	5	7	5		0.83	2.50	10.40	12.48	14.56	14.56
Project option meets public expectations and trust	0.06	2	3	3	3	3	3	4	3	4	3	6	3		0.36	0.54	0.54	0.72	0.72	1.08
Project option meets advocacy group(s) expectations and trust	0.45	1	2	2	3	4	4	5	5	7	5	8	4		0.89	2.68	7.14	11.15	15.61	14.27
	1.00													Total	2.24	6.18	20.03	26.69	33.62	32.64

SENSITIVITY ANALYSIS

We conducted sensitivity analyses to test the robustness of the risk assessment, examining two scenarios.

Design-Build Procurement Values

Caltrans could choose to use the design-build approach for the alternatives requiring significant design. To investigate this approach, we evaluated the risk related to the alternatives assuming a design-build procurement strategy was followed. Table C-8 summarizes our results.

Table C-8. Risk Assessment Results for Design-Build Procurement

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	3.2	4.1	5.2	5.4	5.4	2.8
Environmental	0.1	0.8	1.7	2.5	2.4	2.7
Management	2.9	6.8	5.6	5.6	5.6	4.3
Acceptance and expectations	1.1	3.0	9.6	12.8	16.2	15.7
Risk total [a]	7.3	14.7	22.1	26.4	29.6	25.5

[a] The columns may not add up properly due to rounding of individual risk issue values.

In this analysis, we evaluated the management risk issue area, assuming the design-build procurement strategy. The updated management risk issues are as follows.

Management Risk Issues	Weight	Alt 1		Alt 2		Alt 3		Alt 4		Alt 5		Alt 6	
		P	I	P	I	P	I	P	I	P	I	P	I
CALTRANS (for Design-Build) has the required organizational and business competencies/skills, capabilities, and availability to manage the project	0.10	1	5	9	5	9	5	9	5	9	5	6	5
Industry (for Design-Build) has the competencies / skills, capabilities, and availability required to manage the project	0.13	1	5	4	5	5	5	5	5	5	5	3	5
Modifications are not necessary to existing contracts for each option	0.03	1	1	9	2	9	4	9	4	9	5	9	3
3 (or more) bidders can be obtained for the project option	0.18	5	5	4	5	2	4	2	4	2	4	1	3
Obtaining payment and performance bonds for each project option	0.56	9	5	9	5	7	5	7	5	7	5	6	5
	1.00												

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
	0.52	4.64	4.64	4.64	4.64	3.09
	0.64	2.54	3.18	3.18	3.18	1.91
	0.03	0.45	0.90	0.90	1.13	0.68
	4.53	3.62	1.45	1.45	1.45	0.54
	25.38	25.38	19.74	19.74	19.74	16.92
Total	31.08	36.63	29.90	29.90	30.12	23.13

Acceptance and Expectation Risk

Because meeting the expectations of the public and gaining its acceptance pose significant risk for certain alternatives, we examined the scenario of eliminating this factor from consideration. We selected this risk driver to test for sensitivity since it had the most significant effect on the outcome.

The new weighting factors were as follows:

- Technical, cost, and schedule risk = .490
- Environmental risk = .150
- Management risk = .360
- Acceptance and expectation risk = 0.0.

Table C-9 presents the results of our analysis.

Table C-9. Reduced Scores for Probability and Impact for Acceptance and Expectations

Issue	Alternative					
	1	2	3	4	5	6
Technical, cost, and schedule	6.2	8.0	10.0	10.5	10.3	5.3
Environmental	0.2	1.5	3.2	4.8	4.7	5.2
Management	5.6	5.7	4.1	4.1	4.2	2.5
Acceptance and expectations	0.0	0.0	0.0	0.0	0.0	0.0
Risk total [a]	11.9	15.2	17.3	19.4	19.2	13.0

[a] The columns may not add up properly due to rounding of individual risk issue values.

Appendix D
Abbreviations

AHP	analytic hierarchy process
BTH	Business, Transportation and Housing
Caltrans	California Department of Transportation
EDAP	Engineering Design Advisory Panel
EIS	environmental impact statement
FHWA	Federal Highway Administration
IRT	independent review team
NEPA	National Environmental Policy Act
PRT	peer review team
PS&E	plans, specifications, and estimates
SAS	self-anchored suspension
SB	Senate Bill
SEE	significant earthquake event
SEIS	supplemental environmental impact statement
SFOBB	San Francisco–Oakland Bay Bridge