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The Most Expensive Bridge in the World

This commentary is a response to the “Notes from the Editor” in the June 2004 issue of *Modern Steel Construction*. Recent information for the continuing increase in the cost of the new San Francisco-Oakland Bay Bridge East Span has reopened the discussion of this already controversial project. Vital for everyday commutes, this bridge is the main highway link in the San Francisco Bay Area, and its retrofit or replacement is long overdue.

The California Department of Transportation (Caltrans) made this replacement the largest and most expensive bridge project ever undertaken in California. Caltrans tries to explain the cost increase from $1.4 billion at project selection in 1998 to the current estimate of $4.0 billion with the uniqueness of the suspension bridge section and the recent increase in the cost of steel.

A more careful analysis and comparison with other large bridge projects shows that, unfortunately, the only thing extraordinary about this bridge is its cost. The new East Span has two distinctive sections, one being a suspended structure with 385-m span and other a “Skyway” with multiple concrete 160-m spans. The costs for both sections significantly exceed the cost estimate presented in 1998, which could indicate inefficient design and project management.

Comparing the cost of the new bridge against others, one can see that almost all super-long span bridges were built for significantly less than the new Bay Bridge. The increase in the cost of steel could account for about $120-150 per ton structure, but it can in no way explain $30,000 per ton structure.

Caltrans must respond to many questions related to the bridge design and project management, and in spite of the current late state in the project development there are still opportunities for saving a lot of California taxpayers’ money.

—R.V.M.

Piers for the replacement of the almost 70-year-old East Span already were appearing above the water when discussion of the project started anew on the pages of technical magazines. Discussion was spurred by the updated cost estimate for the entire new span, published by the California Department of Transportation (Caltrans), based on the bid for the suspension bridge portion (*San Francisco Chronicle*, 5/27/04). The new cost estimate comes to $4 billion, which is almost three times Caltrans’ original estimate of $1.4 billion at the final design selection in 1998.

According to Caltrans, the increase in cost is due to the unique design of the suspension portion of the bridge and the recent increase in the cost of steel. Not mentioned in this explanation, the concrete “Skyway,” about 84% of the length of the bridge, also significantly exceeds the early cost estimates.

It is therefore important to reconsider major parts of this controversial project.

During the 1989 Loma Prieta Earthquake, the East Span of the Bay Bridge sustained relatively little damage. The bridge was quickly repaired, but the event triggered a long overdue study of the structure’s capability to resist strong earthquakes. The bridge is located about 12 km from the San Andreas Fault and less than 10 km from the Hayward Fault, each of them capable of producing earthquakes with magnitude exceeding 7.0.

The San Francisco-Oakland Bay Bridge is one of the busiest crossings on the West Coast. When built in 1936, the bridge was the longest in the world (4.36 miles). It also had the deepest foundation and the third-longest cantilever span ever built. The tunnel on Yerba Buena Island divides the Bay Bridge in two. The West Span suspension structures connect the island with San Francisco, and the East Span connects it with Oakland. Built in just 3½ years during the Great Depression, the Bay Bridge is one of the engineering marvels of the 20th century. The double-decker bridge has five vehicle lanes on each deck and 280,000 vehicles use it daily. It is considered the “workhorse” of the Northern California transportation system.

Bridge Replacement and Renovation

Controversy plagued the replacement of the East Span from the beginning. The public expected a fast decision for fixing the bridge, but following the Loma Prieta Earthquake, it took Caltrans seven years to complete an engineering study and to publish recommendations. The recommendations called for reinforcing the suspended portion (the West Span) and for replacing the East Span. The higher cost of reinforcing the East Span, and the significant traffic difficulties of such a reconstruction, motivated Caltrans’ recommendation to replace the East Span. On this point, most specialists have concurred.

The public disliked Caltrans’ initial proposals for replacing the East Span. Subsequently, the Metropolitan Transportation Commission (MTC) created a Design Task Force and an Engineering and Design Advisory Panel (EDAP) to review alternatives and to advise MTC. EDAP accepted the concept to retrofit the West Span and to replace the East Span but rejected Caltrans’ and other hastily prepared proposals. A national or even international competition for the new bridge was then proposed.

Ignoring this, Caltrans hired T.Y. Lin International and Moffat & Nichol to design the new East Span. Despite critical comments and objections during the EDAP review, and explicit concerns that no valuable solutions had been presented, MTC approved a final design concept in 1998.

The final design calls for a suspended "self-anchored" bridge just east of Yerba Buena Island, attached to the so-called "Skyway," a concrete multi-span portion with 160 meter-bays. This suspended bridge is asymmetric, with one main (385 m) span and one side (180 m) span. Unlike the existing double-decked Bay Bridge, the replacement East Span will be built with two parallel single-level decks. The cost of the replacement bridge was the most controversial issue at the early stages. By not providing construction quantities and therefore a reliable cost estimate, Caltrans and its design team repeatedly resisted any attempts by EDAP to challenge the efficiency of the final design.

The cost estimate for the entire East Span project presented by the Design team and Caltrans in 1998 totalled $1.4 billion. Some of EDAP's members were already arguing that this cost was too high in comparison to similar bridges built in the previous years both in the United States and overseas. In spite of the conflict of interest, Caltrans had the opportunity to play the combined roles of Owner, General Contractor and Supervisor of the whole process by setting the bridge systems, the budget and the construction time. Not surprisingly, the cost escalated, growing to $2.4 billion in 2001 and reaching $4 billion in June 2004—while the projected construction time continued to be extended.

Time alone can serve as the final judge of the engineering accomplishment. However, we evaluate a bridge achievement by length of the major span, the quantity of material and the cost used per unit deck.

Bay Bridge Statistics	Existing Span	Replacement/New Span
Total Length (feet)	11,287	11,525
Main Span (feet)	1,400	1,263
Traffic Lanes	10	10
Vehicles per day (average)	280,000	300,000+
Construction Time (years)	3.5	5.0?
Completed/ Estimate Completion	1936	2008?
Total steel for superstructure (tons)	167,100	104,200 (with concrete for 84% of the bridge)
Steel (psf)	119	289
Cost (in million dollars)	78	3,600+

Uniqueness of structure…?

Length of main span. The longer the bridge, the greater the achievement. The longest span of the new bridge is 385 m, a relatively modest span next to the 1930s Golden Gate Bridge (main span of 1280 m) and the West Span of the Bay Bridge (main span of 704 m). It is even shorter than the 427 m main span of the East Span that is to be replaced. Today there are hundreds of bridges around the world with longer spans. The 160-m continuous "Skyway" structure also does not present anything that qualifies for uniqueness.

Structural System. A self-anchored bridge, which is a hybrid between a suspension and a cable-stayed bridge, is considered a novelty. However, the fact that few such bridges are built should have made the designers more careful in their system selection. The "Skyway" is a segmental concrete continuous system—the most commonly used system for concrete highway bridges with spans between 80 m and 200 m.

Efficiency of material use. For both the suspension and the concrete "Skyway," the quantity of material use exceeds almost all contemporary bridges, including those with spans several times longer.

Cost Efficiency. The cost per square meter and the cost efficiency factor exceed significantly almost all other bridges.

It is clear that nothing is unique in this bridge. Both sections are designed with significantly more material (steel and/or concrete) and for a higher cost than almost all long-span bridges in the world. The location, near active seismic faults and deep water, does not provide a valid excuse. Many bridges are built in similar or more violent seismic areas than the San Francisco Bay and in even deeper water. These include the Golden Gate Bridge, the existing Bay Bridge, the Akashi-Kaikyo, the "25 of April" Bridge at Lisbon, and the Gulf of Corinth Bridge.

The main span for the suspension bridge of the East Span is modest when compared to other bridges, and therefore the steel and cost should have been proportionally lower. In light of these considerations, the new East Span will be unique only its excessive quantity of steel and its excessive cost.

The increase in cost of steel?

Can the recent increases in the cost of steel material explain the extremely high unit cost for the East Span? The cost of "raw" structural steel products has increased by 22% from 2003 to May 2004. However, the cost difference is $122 (rising from $567 to $689) per ton. The cost of the steel material, plates, wide-flange beams and others do not have an impact on production cost, welding, labor, assembling, transportation, erection and finish work. Thus, the significant increase of steel material can explain only an increase in the range of $120 to $150

Material	Unit	2001	2002	2003	March, 2004	May, 2004	May, 2004/ 2001	May, 2004/ 2003
		$	$	$	$	$	%	%
Reinforcing Bars	cwt	24.60	24.00	24.52	30.28	34.20	39.0	39.5
Structural Shapes Avg.	cwt	26.57	27.00	25.71	29.04	31.27	17.7	21.6
Reinforcing Bars	ton	492.00	480.00	490.40	605.60	684.00	39.0	39.5
Structural Shapes Avg.	ton	531.40	540.00	514.20	580.80	625.40	17.7	21.6
Reinforcing Bars	metric ton	542.33	529.10	540.56	667.55	753.97	39.0	39.5
Structural Shapes Avg.	metric ton	585.76	595.24	566.80	640.22	689.38	17.7	21.6
							Cost Difference	
Reinforcing Bars	metric ton	542.33	529.10	540.56	667.55	753.97	211.64	213.40
Structural Shapes Avg.	metric ton	585.76	595.24	566.80	640.22	689.38	103.62	122.58

The costs listed in table above are based on McGrow-Hill, *Construction Economics*, *ENR*—given originally in $/cwt or $/100 lbs; 1 ton = 2000 lbs; 1 ton = 20 cwt; 1 metric ton = 1000 kg; 1 metric ton = 2204.6 lbs.

Bridge	Year	L max	Total Steel	Steel	Steel Efficiency	Cost	Cost	Cost Efficiency	Cost Str. Steel
		m	Tons	kg/m^2	kg/m^3	$ million	$/$m^2$	$/$m^3$	$/ton
SUSPENSION BRIDGES									
Akashi-Kaikyo, Japan	1998	**1990**	193300	**1648**	**0.83**	4300	**36658**	**18**	**22245**
Great Belt East, Denmark	1997	**1624**				950	**13061**	**8**	
Humber Estuary, UK	1981	1410		451	0.32				
Verrazano Narrows, US	1964	1298		584	0.45				
Golden Gate, US	1937	1280	66040	1226	0.96	35	non comparable		non comparable
Hoga Kusten, Sweden	1997	1210	14000	437	0.36	125	3901		8929
Bosphorus First, Turkey	1973	1074		365	0.34				
April 25th, Portugal	1966	1013		476	0.47				
Kwang Ahn, South Korea	2000	500	29710	688	1.38	196	4537	9	6597
Yongjong, South Korea	2000	**300**	35100	**1140**	**3.80**	270	**8766**	**29**	**7692**
(Self-anchored)									
CABLE-STAYED BRIDGES									
Tatara, Japan	1999	890				606	15165	17	
Gulf of Corinth, Greece	2004	**560**				740	**9957**	**18**	
Fred Hartman, US	1996	381	5043	141	0.37	91.3	2549	7	**18104**
Existing Bay Bridge, US	1936	704	151593	579	0.82	78	non comparable		non comparable
Existing Bay Bridge, US	1936	427	151593	579	1.36	78	non comparable		non comparable
Bay Bridge East Span	2008	**385**	43420	**1410**	**3.66**	1575	**51148**	**133**	**36274**
Bay Bridge (ES) Skyway	2008	**160**	*60780	***573**	***3.58**	1500	**14140**	**88**	not applicable

Notes:
1. Bay Bridge East Span is the San Francisco - Oakland Bay Bridge
2. **Steel Efficiency** and **Cost Efficiency** are accounting the length of the main span and are equal to the Steel/m^2 and Cost/m^2 divided by the length of main span
3. Bay Bridge (ES) Skyway: *573, *3.58 and *60,780 tons: these values are for reinforcing steel of superstructure.
4. ES indicates East Span
5. The Structural Steel cost is total cost of steel bridge including foundations, temporary structures, etc.

per-ton completed structure, or 1% of $15,000 per ton. While the East Span unit cost is around $32,000 per ton (the highest of all bridges), the increase in the cost of steel represents less than 1% of the total cost and therefore can hardly be accepted as an excuse for the most recent Caltrans estimate.

The "Skyway" Bridge

The mostly concrete "Skyway" section uses 623 kg/m^2 reinforcing steel for the superstructure alone. If designed with steel, the same bridge would use about 420 kg/m^2 with orthotropic steel deck or about 260 kg/m^2 with composite concrete deck. Both steel options could have saved tens of thousand of tons of steel (and dollars), without even considering the cost of concrete. The considerable saving of dead weight could have simplified and reduced foundations and substructure—and saved an additional good percentage of the cost.

The total cost of the "Skyway" will probably exceed $1.5 billion, because the bid for its superstructure alone is $1.1 billion. This also means that, by itself, the "Skyway" will exceed the 1998 estimate projected by Caltrans and the design team for the entire new East Span.

It appears that the new Bay Bridge East Span will be the most expensive bridge ever built, for years to come. While a bridge's main function is to transport people and vehicles in the most efficient way, the current exorbitantly expensive plan for replacing the East Span of the already-congested Bay Bridge does not envision the addition of even one extra traffic lane. Uniqueness should not be a self-serving goal if it fails to deliver higher performance.

These are questions that should be addressed by MTC, Caltrans and the design team, and the answers should be supported by engineering data. One might think this is merely an academic exercise, as the bridge is already under construction. However, it is very important to understand why the bridge is so expensive so the same mistakes are not repeated. Moreover, the bridge has two separate parallel decks and it is not too late to revise the project and replace at least the extremely expensive "Skyway" with one deck. The suspension portion also can be redesigned. Caltrans has protracted construction time for years. There still is the chance that a better-designed option will overcome the delays—and maybe even save some time—and still reduce the cost significantly. ★

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