From "High Steel" — The Building of the Bridge

The first construction work (on the San Francisco-Oakland Bay Bridge) was begun in May of 1933, though the formal groundbreaking by Hoover and Governor Frank Merriam had to wait till July 9. The Governor ceremoniously hefted a clod or two in his gilded shovel and the ex-President orated about "the greatest bridge ever made by human hands."

President Franklin D. Roosevelt pressed a telegraph key as 12:47 which detonated charges on Rincon Hill, on Army Point of Yerba Buena Island, and at the foot of Oakland's 14th Street. Hardly had the echoes of the explosions died away before excavating was begun and, by November, there were gaping gashes in the island, awaiting piers and anchorage.

Purcell knew the limits of his art. No one could lay a single suspension bridge across the 9,250 feet of deep water between Rincon Hill and the island. He would have to build not one but three, all rolled into one.

It would be easy to connect Yerba Buena Island with the Oakland shore by a conventional bridge. But the west crossing would have to be two 2,310-foot suspension bridges (with 1,160-foot sidespans) connected at a common anchorage. (Only one such tandem bridge existed, a small one built in Prague in 1841 across the Moldau River made famous by the composer Smetana.)

To form a mid-stream superpier, he would have to plan a brand-new, man-made, island in the Bay. Thus, the suspension span would have five piers but only four towers. Pier W-4, to be built by Moran & Proctor Construction Company, would be a double anchorage.

Luckily for Purcell, he found an underwater ridge of rock. It ran all the way to the island, but lay beneath 100 feet of water and another 100 feet of mud. The bridge's foundations would have to be deeper than any ever built. And he could not dump rock to create his island; such loose till would never provide his cable with the grip they needed on Mother Earth. Nor would a concrete atoll serve.

His anchor pier would have to be a high island of concrete to take the live and dead loads of the span and survive possible earthquake shocks. It must support a deck 261 feet above busy shipping lanes. At 92 feet by 197 feet, the size of the caisson he intended to use to build it, and extending 210 feet below water, it would not only be higher than the City's tallest skyscraper, the 33-story Russ Building, it would be the largest pier in the world.

Since the "island" was the key to the success of the entire bridge, Purcell sought the help of 70-year-old Daniel E. Moran, the expert on deep-water foundations. They pored over contour maps, sections (profiles) of the Bay bottom, and boring cores. The 200-foot combined depth was twice the range of "sand hogs" (laborers) working under pressure, but they finally came up with a plan.

Workmen laid the keel, as it were, for "Moran's Island" when they built a pneumatic or compressed air caisson on the shipways of the Moore Dry Dock Company in Oakland. The Moran and Proctor caisson was half the size of a city block. Its four timber walls (ending at the bottom in sharp cutting edges of steel) sheltered, topside, five rows of eleven vertical steel cylinders, 15 feet in diameter.

The cells were open at their bottoms but sealed at their tops with hemispheric, airtight domes, which gave the caisson its buoyancy. Towed to the site, the great caisson was wedged between two working platforms. By pouring concrete around the cylinders, the structure was sunk slowly in place as workmen extended upward its walls and cylinder tops to keep them always above the water level of the Bay.

When the caisson was supported by the Bay floor, the welded domes were removed in sequence, and clamshell buckets dropped down the tubes to dredge up the mud trapped between the watertight walls of the great box, 6,800 pounds of muck at a gulp. After the caisson rammed the cutting edges down into solid rock, divers cleaned the rock's surface.

Next, sharp-pointed gads were dropped down the chutes to break up the rock to permit leveling for a good footing. The square chamber at the caisson's bottom was then filled with concrete to make the caisson an integral part of the pier. The watertight concrete mat was extended up into most of the cylinders for only 35 feet. Beyond, they were left filled only with water. Corner cylinders were plugged completely.

Pier W-4, which grew out of the caisson, consumed more concrete -165,000 cubic yards - than the Empire State Building or six Russ Buildings. "Moran's Island" is the size of a 40-story building covering a city block, far bigger than the largest of the Pyramids of Gizeh.

Tour boat operators today will tell you that "Moran's Island" is the tomb of from 4 to 7 workmen who fell into the fresh concrete and were buried alive. According to the unofficial historian of the Bay Bridge, Charles Seim, the actual total was - zero. The story is a dramatic one, but it is totally untrue.

The other piers of the suspension span were formed in the same fashion as W-4. At 240 feet, W-3's maximum depth was even greater than that of the anchorage-island, but no serious difficulties were encountered as new records were set for subaqueous construction.

Purcell and Moran must share honors with Bill Reed, chief diver, for the bridge's success. He was paid $15,000 a year, a fabulous Depression salary, plus a dollar-a-foot for each dive made. He earned every penny. The west Bay piers ranged from 100 to 240 feet in depth, the 23 east Bay piers from a mere 50 to 242 feet at one end of the cantilever span. Six of the piers penetrated deeper under water than any on the globe.

No diver, not even Reed, could work steadily at the Bay depths. With pressure mounting to 100 pounds per square inch (from the 14.7 pounds of normal atmospheric pressure) he could only dive for 10 to 15 minutes at a time. But that was enough time for him to inspect the critical underpinnings of Purcell's bridge. Reed's hands and fingers became Purcell's underwater eyes. There was no light on the bottom; he had to work blind. Reed substituted his marvelously developed sense of touch for sight.

A delicate job for Reed was pier E-5, where ten feet of bottom was excavated beneath the caisson. It was his job to crawl under 56,000,000 pounds of concrete to see if dredge buckets and water jets had done a good cleaning job. In 21 days, Reed made 23 deepwater dives. According to Purcell, they varied from 170 to 185 feet. In just one day, he made three 170-foot dives, a new record for the Bridge.

Typical of Reed's hazardous duties was his straightening of a canted caisson hung up on an obstruction in the mud, and tilting dangerously. Work was suspended while Reed's fingertips groped along the "hull" of the caisson, found a projecting rock, planted a dynamite charge -

and got out of there. When the detonation removed the offending bump, the caisson swung neatly back into place.

Each time he dove, Reed took his health, perhaps his life, in his hands. The age-old danger of the bends required that he be rushed into a decompression chamber after each dive, where the air pressure would gradually be decreased to normal. There was always the chance of an accident as he squeezed between thousands of tons of steel or concrete in tide-swept, choppy, waters.

He also found the Bay bottom to be a junkyard of anchors, cables, and jetsam. He had to pick his way blindly through the debris and, once, had to cut his lifeline when it became badly tangled in a rusty old cable. He was hauled to the surface on his air hose.

Across the marshy shallows of the Oakland shore, with its pickleweed and duck blinds, Purcell ran a series of simple plate girder spans and through-truss spans from a viaduct and terra firma. The dry land piers of Yerba Buena Island were easy enough, as were the 20 shallow water piers, the latter founded on timber piles and built within sheet-pile cofferdams.

By February 1935, the two-boom traveler derrick advancing along the deck had replaced falsework with permanent bents (supports) and truss panels as far as the deep water immediately behind the island.

Purcell chose to cross the channel with a huge cantilever span (1,400 feet long, 22,500 tons, and 191 feet above the water), the largest and heaviest in the U.S., but cheaper than a suspension bridge in that location. It was built by a guy-derrick traveler - a gigantic metal spider - creeping forward and devouring steel from barges below.

Half of the span was up by January 1936. The main problem was pier E-3 at the deep end of the cantilever structure. It was 300 feet down to bedrock. It would be difficult to sink a caisson there, impossible to send a diver - even Reed - that deep. So Purcell planted the pier on a solid substratum of hard clay and sand. Even so, at 242 feet, E-3 was the deepest pier in the world. A 16-story building set alongside its base would not break the water with its lightning rod.

To support the west Bay's suspension span cables, four steel towers were erected on Piers W-2, W-3, W-5 and W-6. (Moran's Island," W-4, was an anchorage, of course, without a tower.) W-2 and W-6 rose 474 feet, but the other two soared to 519 feet in order to bring the bridge floor to its highest point, 216 feet above harbor traffic, at the anchorage pier.

Each tower was built of two cellular columns, or legs, of silicon steel joined by X-shaped crossbraces and horizontal supports, or struts. The flexible towers could take a load of 65,000,000 tons. Their tops could bend four to five feet out of line in obedience to load and temperature extremes. Sections of the towers, averaging 50 feet in height and 75-80 tons, were shipped by train from the east and towed by tugs to their piers on railroad car floats.

The usual creeper traveler, a derrick which clung to the surface of a tower and moved upward like a second-story man, could not be used because of the design of the tower legs. Instead, the engineers of the American Bridge Company used the center cell in each leg as a well or shaft to hold a 180-foot vertical steel mast. On top of it was a small rotating mast fitted with the crossarm of a hammerhead derrick. It was served by a stiff-leg derrick set between the bases of the two columns. After four tower sections were placed, one atop the other, the hammerhead was raised 50 feet and the operation repeated.

The hammerheads "committed suicide" by erecting guy derricks which promptly dismantled them. These guy derricks then placed the grooved cable saddles on the tops of the columns. The saddles were the largest single-piece castings ever used in bridge work.

When the first saddles arrived, it was March 1934, and a bloody waterfront strike was paralyzing the Embarcadero. Purcell preferred to take risks rather than submit to costly delays, so he ordered the ship to " dock" at a bridge pier where a stiff-leg offloaded its critical cargo and passed the saddles up to the guy derrick above. (The guy derricks were left in place to help with cable spinning.)

Towers were built one at a time, each taking three 5-day weeks of two 6-hour shifts of workmen. Not until each entire 5,000,000-ton tower was erected were temporary bolts replaced with 110,000 hot field rivets.

At the ends of the sidespans, the cables would rest on short inclined steel columns which rotate on huge pins at the bottom. These were the cable bents which provided the support for the cable between the end towers and the anchorage.

Beyond them the backstay cables extended to the anchorages, great concrete monoliths sunk deep into the rock and entombing tiers of steel eyebar chains which grasped the splayed-out cable strands firmly. Since the cables stretched and shrank with load and temperature variations, the bents rocked on great pins at their bases.

On the anchorage pier, W-4, each cable, splayed into strands like an unraveled rope, was tied by eyebars to a 40-foot high steel A-frame. Its legs were anchored to "Moran's Island" by chains of eyebars extended to girders imbedded 135 feet deep in the concrete, to handle the tremendous pull of the cables. Collars called splay castings prevented "unraveling" of the cables beyond their proper splay points.

Each of the four 28 3/4-inch cables consisted of 17,464 galvanized (.195 inch) wires in 37 strands of 472 wires each. In all, 18,500 tons of spliced wire (thousand of miles of it) with a tensile strength of 220,000 pounds per square inch, was used on the Bay Bridge.

Before the "aerial spinning" could begin, two 10-foot catwalks for workmen had to be slung from the towers in curves corresponding to those of the future cables. To cut down on weight, wind resistance and fire hazard, American Bridge engineers used strips of galvanized chain link fencing stapled to timber crosspieces and "paved" with fine mesh hardware cloth.

Sections were hoisted to the tower tops, spliced together, and slid down the catwalks' support ropes or cables. Storm cables held the footwalks safe from excessive wind sway and the crosswalks connecting the parallel catwalks acted as stiffeners. Naturally, the catwalks were tempting to would-be "bridge monkeys" who had had a few drinks. One of the first to make his way to Yerba Buena Island and back on the cyclone fencing was George Christensen of San Francisco.

Frugal Purcell later cut the catwalk support ropes into short lengths for suspenders for the deck's trusses, and used the storm cables as permanent hand ropes atop the finished cables for inspection walkways.

Timber gallows frames (squared-off, inverted "U"s) on the catwalks carried sheaves for the powered, endless, hauling ropes on which the spinning wheels rode. Electric lights on the footwalks allowed spinning to be done at night, weather permitting, though (curiously) it was not carried on during Saturday afternoons or Sundays.

To begin spinning a cable, men first made fast the ends of wire on two reels to the anchorage. The wire was then looped over a large pulley-like wheel with two grooves. Hauled across the Bay, the wheel laid down four wires, each trip, or be looped around horseshoe shaped castings called strand shoes, which were connected by pins to the anchoring eyebars. The two lower, inert, wires were the anchored "dead wires", the upper one the "live wires" advancing from the reels continuously along the growing cable. Each group of four strands was called a "set-up". As each reel was emptied, the ends of the wires were spliced to the ends of the next reel, making endless loops of wire.

An innovation by Purcell was to add companion wheels working from the opposite end of the span. Both were fed by reel stands of four active spools, or reels, at each anchorage. The wire passed from them to the spinning wheels via counterweight floating sheaves which maintained proper tension on it.

The main cables were completed and pneumatic squeezers were busily compacting them (by January 1936) and changing their shapes from hexagonal to circular. Six screwjacks, mounted on a yoke or collar surrounding each cable, advanced and squeezed with great pressure, then ran a few turns of temporary seizing wire around the cable to hold its shape for the wrapping machines.

The latter were also yokes, but with bobbins instead of jacks, which crawled along the cables they surrounded and wound a tight spiral of soft, annealed galvanized wire around them for permanent protection.

Near the 596 cable bands, from which would hang the 1,192 suspender ropes holding the deck trusses, the wrapping was done, painstakingly, by hand, with men tucking the wire under the grooved edges of the cable bands and caulking the remaining space with lead wool. Lastly, the wrapping was sealed with paint.

The westernmost of the twin suspension cables was spun first, then the equipment moved to the east span on November 12, 1935. When its cable was completed on January 20, 1936, a average of 128 tons of wire had been laid per day, easily beating the George Washington Bridge's old record of 99 tons.

The stiffening trusses supporting the bridge's two decks, and preventing twisting of the span from live load (traffic) changes ranged from 75 to 200 tons each. They were barged to the bridge in one of the most difficult peacetime "fleet operation" in our history.

Tidal currents were too powerful for the engines of tugs to hold the barges in place long enough to attach the lifting apparatus. (They could not anchor for fear of dragging - and breaking - power and communication cables on the bottom.)

Finally, four widely spaced anchors were planted where they would not foul cables. Lines attached to them were run to the drums of hoisting machines on a special anchor barge. This could be planted securely in four sets of falls attached to struts laid across the cables, required but ten minutes' work by the four hoisting engines at the nearest tower base to raise and position the trusses. But men had to guide them into perfect alignment and bolt together their chords (horizontal members). This factor, plus the vagaries of wind and wave below, kept progress down to two units per day, three on a very good day.

The heavy truss units were placed in position in a strict sequence with deliberate gaps left in the span in order to avoid an unbalanced pull and, thus, excessive tower deflection and cable distortion. (Stringers, curbs, concrete, etc., were later added in a staggered order, also for the same reason.) Daily measurements showed a maximum tower deflection of only three inches, thanks to Purcell's precautions. All of the 146 two-panel units were raised between December 18, 1935, and April 30, 1936.

Once the trusses were all in place, three 14-ton guy derricks began to run on the upper deck level, placing the balance of the crossbraces and the floor steel. They were followed by riveters who replaced the bolts in the chord joints.

A routine operation, which was critical nevertheless, and even "ceremonial," temporarily caused a problem for the engineers. The time came for the twin halves of the span cantilevered over the channel (east of Yerba Buena Island) to meet and be bolted together, completing the final link of the bridge.

Meet they did, as the closing members were hoisted into place by the huge inset-like guy derrick travelers. But they refused to fit! As workmen scrambled over the steel like bugs, the engineers found that the pinholes of the lower chords were short of matching by 10 inches those of the upper chords by 13 inches.

Apparently, a cool sea breeze was shrinking one side of the span on a sunny warm day. To connect the lower chords the entire structure was jacked 10 inches westward from the expansion joint of pier E-4. When the chord holes matched, a triumphant gang of hard hats swung a battering ram to drive home the last chord pin. The 3-inch gap in the upper chords was closed by jacking and by extension of these members. And perhaps the weather changed (it always does on San Francisco Bay) to help, rather than hinder.

West Bay and east Bay crossings were connected by the world's largest and longest vehicular tunnel, a double-decker drilled and blasted for 540 feet through Yerba Buena Island. Three "pioneer" tunnels were first bored, then broken out by excavation to create an arch which was concreted. Then the core was excavated and the spoil dumped into the Bay to partly create Treasure Island. So big was the finished tunnel, 52 feet, 8 inches high and with a clear width of 65 1/2 feet, that a 4-story house could have been constructed inside it.

Paving of the two bridge decks was done in short, alternating strips of concrete poured into wooden forms. The upper level became a six-lane "automobile boulevard" for cars and buses. The lower deck was occupied by three (north side) lanes for trucks and by twin standard-gauge tracks for the electric trains of the interurban Key System. (They were removed in 1958 and the two decks made into five-lane, one-way, suspended highways, the lower level eastbound, the upper deck westbound.)

The last rivet was driven on October 23, 1936. On November 12, after three years and seven months of hard but rapid (two months ahead of schedule) work by an army of men putting in 54, 850,000 man-hours of work, completion was official. Several hundred thousand people participated in a three-day celebration. Some 14 naval ships belched smoke and man-made thunder in a cannonading salute as 250 Navy planes flew overhead.

At the Oakland bridgehead, Rabbi A. A. Stern offered prayers for the 24 workmen who had lost their lives on the bridge. (Purcell did not think the number was excessive.) Ex-President Hoover spoke once again. Purcell, his staff, and a hard hat representing his thousand of buddies, took bows.

Governor Merriam then used a dirty acetylene torch to cut a golden link in a silver chain and Time preserved his rather banal observation: "This bridge is not the product of a day." As the chain hit the pavement at 12:27, 1,500 pigeons were released into the blue sky.

According to poetically licensed Time, some harbor seals popped their heads above the surface of the Bay to see what was going on and then (as if on cue) added their barks to the cheers of the throng. Overhead, the winds toyed with the smoky calligraphy of a sky-writer, his plane lettering "The Bridge Is Open."

Dignitaries raced across the bridge to repeat speeches on the San Francisco side. FDR pressed a golden key in the White House which triggered green lights, and six long columns of cars shifted into first with a nervous grinding of gears you could hear on Rincon Hill. The three eastbound and three westbound phalanxes of autos moved out. Pedestrians lined both rails, but only on that day, for there were no provisions for them, unlike the Golden Gate Bridge.

The largest and most expensive bridge in the world ha a gargantuan appetite. It had swallowed 20,000 tons of structural, cable and reinforcing steel; 1,000,000 cubic yards of concrete; 1,300,000 barrels of cement, and 22,000,000 rivets (give or take a few). It cost 78 million depression dollars and 24 lives.

The decks of both bridges were engineered with a flexibility to accommodate traffic loads and temperature changes. Both have the capacity to move up and down over 20 feet; however, their normal movement is approximately 4-5 feet.

Was it worth it? Absolutely. It probably could not be built today at any price. There are not enough skilled workmen in the labor force and not enough inflated dollars in our coffers.

It is said that a visitor, a distinguished gentleman, was loaded with statistics and information, all true, by Bay Bridge guides. They told him that it took 18 percent of all the steel fabricated in the United States in 1933; that it required enough timber to build houses for a town of 15,000 people; sufficient reinforced concrete to rebuild downtown San Francisco, or create 35 copies of the Russ Building or the Los Angeles city hall; that the 71,000 miles of wire locked into its cable would circle the globe more than three times and, if laid end to end would stretch three-quarters of the way to the moon!

The visitor accepted all these astounding facts serenely. But then he saw a 50-ton cantilever member being lifted into place. Next he watched as a 200-ton stiffening truss unit was snatched up off a barge and deposited like a jigsaw piece into the span 200 feet above his head by slim hoisting lines and skinny suspender ropes. He continued to listen patiently to his proud bridge guide, but shook his head in disbelief. "I cannot believe my eyes. I cannot believe you. It just cannot be so. It's too marvelous."

The Bay Bridge has an inferiority complex because of its homely east Bay crossing via-a-vis the beauty and popularity of Strauss' fairy princess of a span (the Golden Gate Bridge). Visitors cannot flock to it on foot, though many drive across it just for the splendid view.

It is not favored for suicides, having drawn only 126 so far compared to the Golden Gate Bridge's 680 or more. Still, it was blessed by the Pope (in 1936, when he was Cardinal Pacelli) and it was named one of the seven engineering wonders of the world by the American Society of Civil Engineers in 1956.

What more can a bridge ask? Except to be loved, like the Golden Gate Bridge.

Excerpted from High Steel: Building the Bridges Across San Francisco Bay,
by Richard Dillon, Thomas Moulin and Don DeNevi.

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