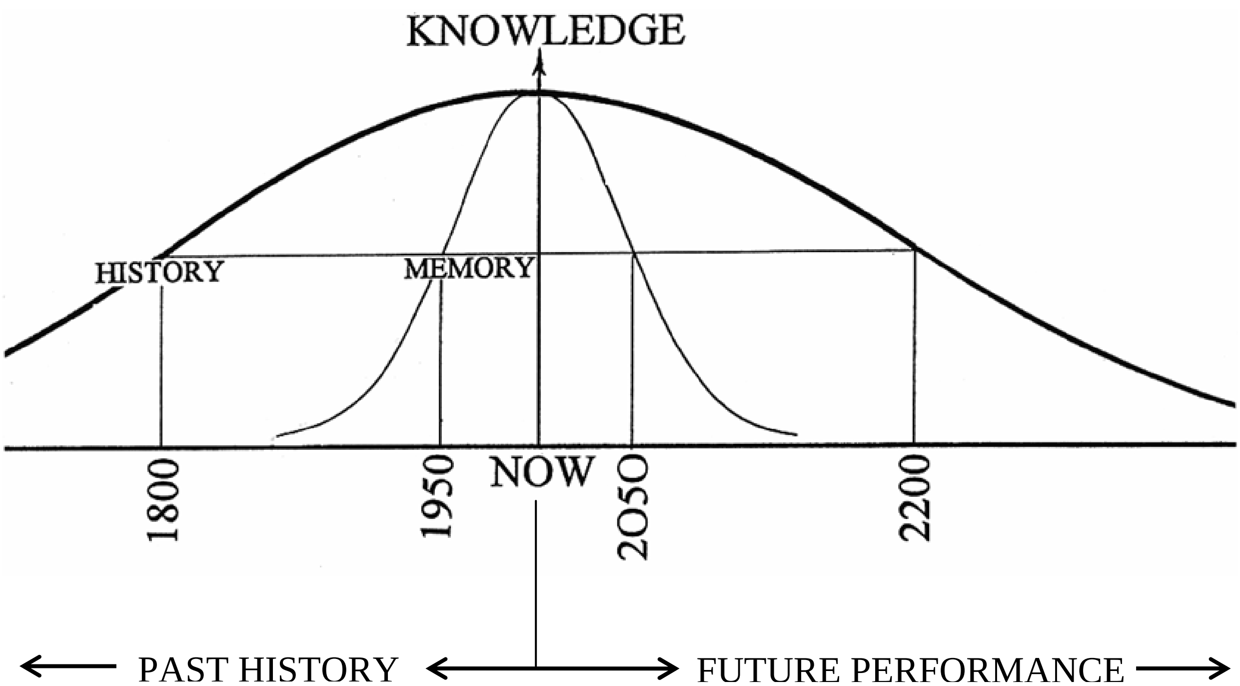
THE STORY OF BURIED STEEL PIPES AND TANKS

By: Reynold K. Watkins



We can make rational recommendations for the future
about as far ahead as our knowledge of the past

We Need History

THE STORY OF BURIED STEEL PIPES AND TANKS

by Reynold K. Watkins*
01 March 2006

Water is the life blood of the arid Great Basin. The Great Basin is a large, dry, lake bed between the Rockies and the Sierras. When I joined the faculty at Utah State, all of the water for irrigation was delivered in ditches. Loss of water was serious. Too much water was sucked up by grass and willows along ditch banks. Too much water seeped into the sandy soil. Too much water evaporated from the warm, wet ditch banks. A ditch, one mile long, could deliver maybe a third of the inflow.

And there was always erosion of the banks, and silting up of the ditch, and rodent holes, and ice-damage to gates. But the worst problem was loss of children. When my neighbor family found the body of their two-year-old in the ditch, they were inconsolable. And so was I. I resolved to learn about buried pipes as alternatives to open ditches.

On sabbatical leave, I studied pipes under Spangler at Iowa State College. The nation had not yet recovered from World War II. So office space for graduate students was limited. But Professor Spangler, graciously invited me to share his office with him. “The office is never locked,” he said, “And the outside door to the building has no lock.” How times have changed.

Professor Spangler was more than a teacher. He was my mentor and my colleague. He would take time to relate his buried pipe experiences and research. On one occasion in his office, Professor Spangler turned to me and said, “I derived a formula for predicting ring deflection of buried flexible pipe — specifically for culverts under roads. I call it the Iowa Formula. But it doesn’t work. Would you care to find what is wrong with the formula?”

I would, and I did. His mathematics were complex and elegant — and correct — except for the dimensions of a “modulus of elasticity” of the soil. We corrected the dimensions and published the Modified Iowa Formula in 1958. I was caught up in pipes.

The legacy of Marston and Spangler is the design of culverts, an essential component of the Interstate Highway System. In fact, the development of buried pipeline systems is connected inextricably to the development of highway systems. It’s all about earth-moving.

After World War II, roads were a maze of disconnected local roads (state, county, town) and at a time of desperate need for interstate transportation. Roads had been neglected during the war.
On 29 June 1956, President Eisenhower signed the Federal Aid Highway Act.
The Interstate Highway System was about to be born.

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But its conception occurred much earlier — after World War I. In July 1919, an army company departed from Washington D.C. in a cross-country automobile caravan. The objective was to evaluate transportation by automobile as the inevitable replacement of horse-and-wagon transportation before World War I. A young officer in the company was Captain Dwight Eisenhower. It took 62 days to reach San Francisco. Captain Eisenhower noted that the wagon roads were a more serious detriment to transportation than were the automobiles — despite tire blow-outs, overheated engines, and broken axles.

After World War II, General Eisenhower surveyed the effect of Allied bombing. He noted that a German railway could be knocked out by a single bomb. But the German Autobahn was indestructible. A bomb could not knock out two parallel multi-lane highways. Moreover, Germany could be crossed in two days.

In 1953, President Eisenhower remembered the 62-days on rough wagon roads across America; and only 2-days on a speedway across Germany. He got onto the case for an American interstate highway system — for rapid deployment of troops and equipment, and for emergency evacuation routes — but also for urgent civilian needs — transportation, and commerce.

Timing was right. The need was obvious. The President prioritized needs of the troops — US — above pork-barrel-politics. And the Know-how was available. Highway technology had been progressing — albeit unnoticed.

Figure 1. Key contributors to transportation in the United States; Dwight David Eisenhower (top), signer of the Federal Aid Highway Act in 1953; and Anson Marston (bottom), first chairman of the Highway Research board, circa 1920.

As for the Know how ?

Before World War I, Anson Marston (Figure 1) was coerced, as his professional responsibility, to become the first Dean of Engineering at Iowa State College. He accepted reluctantly, "But only for two years, mind you." Anyway, why was engineering needed at an ag-college in corn-and-hog country? Dean Marston found out why. Each spring, Iowa farmers were bogged down in roads that were quagmires of mud. See Figure 2. Marston responded with a call for action. "Let's get Iowa out of the mud." He had support from farmers who put pressure on the state government. The Iowa road project was launched.

Figure 2. Reason for Dean Anson Marston's call for action, "Let's get Iowa out of the mud."

Marston realized that to get Iowa out of the mud, they had to get the water out of the roads. And THAT, he declared, could be accomplished by drain pipes and culverts. Marston, himself, led out by deriving a formula for the earth load on a buried pipe. It is simply the weight of backfill soil reduced by friction of the trench walls. See Figure 3. Then it became the responsibility of pipe manufacturers to make pipe that could support the Marston load. The D-load test for pipes became a performance specification . Performance specification was new concept for pipe design.

The Iowa road drainage project was a success. Pipe manufacturers were pleased with the performance specification. They could utilize their own expertise in making pipe that could support the D-load, and not be encumbered by volumes of procedural specs. State highway departments took notice. Iowa was not the only state bogged down in muddy roads. So the Federal Government established the Highway Research Board. Anson Marston was its first director. Highway drain pipes were part of a remarkable development of buried pipes — for culverts and drains — but also for transmission of water, gas, power, and oil; and for disposal of sewage and storm-water; and for subways, and shopping malls. Buried pipes were becoming the arteries of communal life — the guts of civilization's infrastructure.

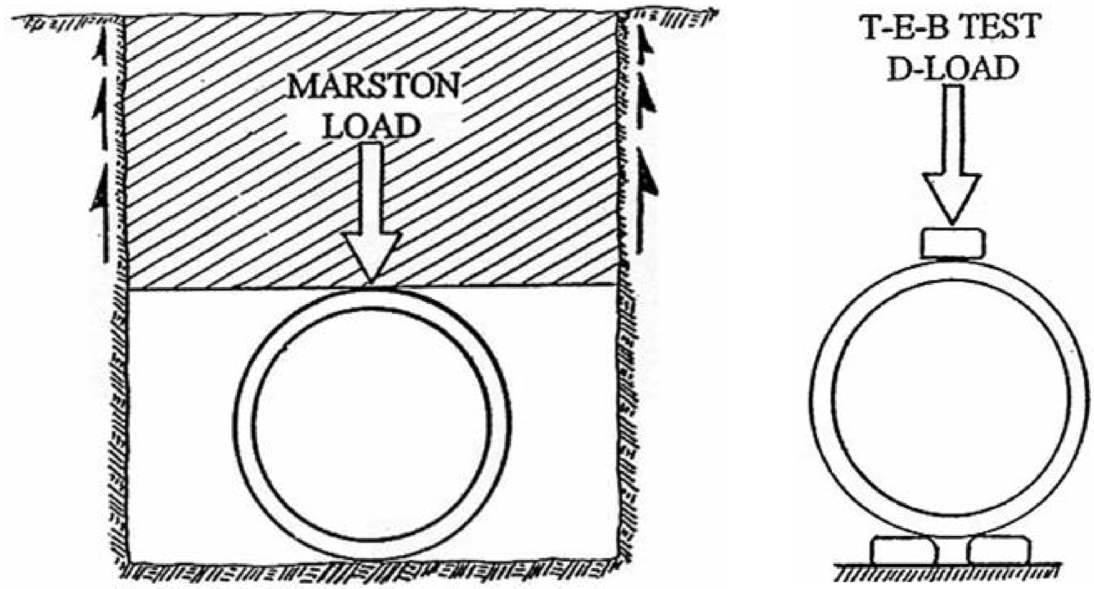


Figure 3. Marston load on buried concrete culverts was the weight of the backfill reduced by friction of the trench walls; and the D-load test for manufacturers to meet the Marston Load requirement.

Evolution of pipes that serve communities originated in antiquity. About 2500 B.C., the Chinese delivered water through bamboo pipes. In Greece, terra-cotta pipes supplied water to villagers at a central well. In Persia, rock-lined tunnels called knanats, were dug by hand to deliver fresh-water from the mountains to the parched cities on the plains.

During 100 to 300 A.D., in Rome, with plenty of low-cost slave labor, pipes became an important part of the infrastructure for the emperor and the elite. Water was delivered to Rome in aqueducts. Then the water was distributed in lead pipes to the mansions of the elite and their luxurious Roman baths. The “Fall of Rome” may have been brought about, in part, by those lead pipes. The acidic water dissolved lead from the pipes. The elite were lead-poisoned. Lead caused impotence, and the few successful births produced heirs who were mentally retarded. Calligula? Nero?

During the Renaissance, the foul smell of raw sewage in the streets of cities, like Paris and London, led to buried sewer pipes. Underground sewers were brick-lined tunnels. The bricks formed arches like the remarkable Roman arches in buildings and aqueducts. Mortar was not needed because the blocks (brick or stone) were held in place by compression. The concept of arching action was “re-discovered” in the 1900's as it applied to soil arching action over buried pipes.

Development of pipes was empirical, labor intensive, and fraught with failures. Who knows how many Persian lives were lost in underground cave-ins while excavating tunnels ahead of rock lining? How could the Romans know that acid water in lead pipes would cause lead poisoning and infertility, and mental retardation of their children.

Iron

Iron had been known since 1000 B.C., but before the Renaissance, iron was used mostly to make spears, swords and shields. By 1346 A.D., iron was used to make guns. These guns became the incentive for iron pipe — the dream of "ingeniators" (engineers) because of the demand for water in burgeoning cities and because iron is stronger than bamboo or clay. Iron pipes became reality in England in 1824 when James Russell invented a device for welding iron tubes (gun barrels) together into pipes.

Costly, hand-made, iron pipes supplied gas for the gas lamps in the streets and dwellings of the elite. In 1825, Cornelius Whitehouse made long iron pipes by drawing flat strips of hot iron through a bell-shaped die. Then came the Bessemer process for making steel, and the open hearth furnace for production of large quantities of steel. Steel pipes became reality. The urban way of life was changed. The community expanded into a metropolis. The "guts of the city" became steel pipes for water; and for sewage, clay pipes and brick-lined tunnels.

Walter Cates identified four stages in the development of steel pipe in his, *History of Steel Water Pipe* (1971).

1. In 1831, the first furnace was built in the United States for making wrought iron pipe. More furnaces were built. The demand for pipes was enormous because of the need for water distribution in fast-growing cities. Pipe production was limited, however, because iron was not available in large quantities.

2. The second stage was the age of steel. Steel was born in England in 1855 with the Bessemer process for making iron into steel. Then the open-hearth furnace (1861) made steel available in thousands of tons — not just pounds. After the gold rush, in California sheet steel was formed into tubes with longitudinal, riveted seams. One end of each pipe "stick" was crimped so it could be stabbed into the next stick like stove pipes. Sections were joined by simply forcing them together. From 1860 to 1900, virtually all water pipe was cold-formed from steel sheets and riveted. Two million feet were installed.

3. The third major development was Lock-bar pipe in 30 foot lengths. See Figure 4. It was first fabricated in New York. Two semi-circular pipe halves were joined by inserting the edges of each into two longitudinal lock-bars with an H-shaped cross section. The edges of the pipe halves were "up-set" to form a shoulder for engaging the lock-bar. The seam was 100% efficient. Three million feet of Lock-bar was installed— and only half as much riveted pipe.

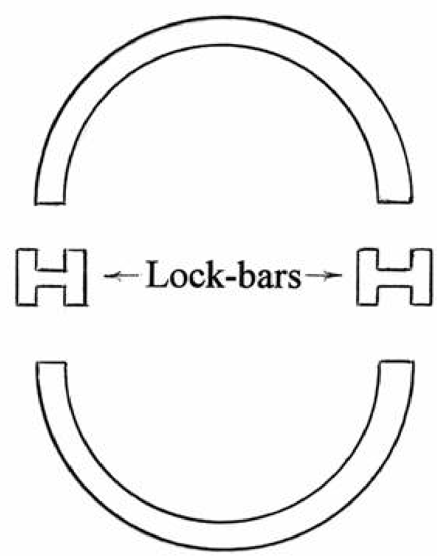


Figure 4. Sketch of Lock-bar pipe.

4. The fourth major development was automatic electric welding. Welding started as a novelty in 1920, but in only 20 years welding took over steel pipe production.

Seven million feet of welded pipe was installed.
But back to the story.

The Marston load applied only to rigid pipes — concrete and clay. The "failure" (or performance limit) was cracks in the pipe. Crack width was limited to 0.01 inch. I was studying rigid pipe design and came upon the unreasonable hundredth inch crack standard. Crack width depends upon wall thickness, pipe diameter, and multiplicity of cracks. I asked Professor Spangler, "Why the 0.01 inch crack for concrete and clay pipe?" Professor Spangler laughed, sneezed, put down his cigar, and said, "Come with me." We walked down the hall to an office with name plate, William Schlick. "Bill, this student wants to know why the hundredth inch crack."
Bill Schlick related this story.

Dean Marston called two students into his office: Ib Spangler and Bill Schlick. To Ib he said, "Spangler I want you to construct a soil box in which you are to prove the Marston load theory." And to Bill, "Schlick, you are to inspect every culvert in Story County and report back to me." The next morning, Bill went into the field and crawled through concrete culverts all day. Late that evening he returned to the laboratory, tired, and covered with mud. Then it occurred to him, that he was supposed to report back to the Dean. But he had nothing to report except that he had crawled through a hundred muddy culverts. Despondent, he happened to notice a scrap of steel shim stock on the floor. It was a half inch wide, 0.01 inch thick. He cut off a few inches, rounded one end, and stuck it in his pocket. The next morning he returned to the field and found how many of the culverts had a crack inside that was wide enough for him to stick in the gage. That evening he reported to the Dean, the percent of culverts with cracks wider than one-hundredth of an inch. "That's good, we'll publish!" The Dean exclaimed. And suddenly, the hundredth inch crack became the standard.

After the Marston load specifications for <u>rigid</u> pipes, comes now Armco Company with <u>flexible</u> corrugated steel pipe. From tests in their yard in Ohio, corrugated steel pipes performed well as buried culverts, but they collapsed under the "standard" D-load. So why did flexible pipes perform as culverts? Dean Marston assigned the flexible pipe question to a young instructor, M.G. Spangler. That was in the late 1930's. From soil box tests, Spangler discovered the effectiveness of soil support at the <u>sides</u> of flexible pipe. It became clear that buried pipe performance is pipe-soil interaction. And soil is a major component of the conduit. Spangler derived his Iowa Formula for predicting flexible ring deflection as a function of pipe ring stiffness, <u>and horizontal soil support</u>. Spangler demonstrated that good embedment is the basic structure. See Figure 5.

Figure 5. Merlin Grant Spangler, Professor, Iowa State University; father of buried flexible pipe design; chairman of the culvert committee of the Transportation Research board.

Production costs of corrugated steel pipes were reduced by forming pipes from coils of steel; helically wound, like toilet paper spools, with welded seams. Coatings evolved from asphalt to zinc (galvanized) to aluminum and to polymer coatings.

Plastic pipes appeared on the scene.

During World War II, German water distribution was damaged by Allied bombs. Steel plants had been destroyed. So, without steel pipes, how could damaged water pipes be replaced? A "quick fix" was temporary replacement using plastic PVC pipe. After the war, "temporary" became permanent. In good soil embedment, plastic pipes survive and for long life. Now, plastic pipes abound in gas distribution, in electrical conduits, in indoor plumbing, etc., etc. Plastic tubes are ubiquitous.

Soil handling and excavating

At the same time as the evolution of pipes, there was an evolution of soil handling and excavating equipment. World War II advanced mechanized equipment phenomenally. The Nazis invaded neighboring nations with "blitzkrieg" (lightning strike) mechanized artillery. Horse-drawn artillery was suddenly obsolete. Steam engines were replaced by diesels. Steam shovels were replaced by backhoes. Mule-drawn scrapers, and fresnos, were replaced by graders, and bulldozers and carry-all-loaders, and gigantic dump trucks. The grade-all was developed for shaping cuts and fills.

Major contributions were the remarkable inventions of R. G. LeTourneau. See Figure 6. Legend has it that LeTourneau sought inspiration from On High in his conference room where a conference table was surrounded by twelve empty chairs with pad of paper and pencil at each place. In this sanctuary, Bob paced around the table. When a revelation descended, he would drop onto the nearest chair and make notes. From his autobiography, *Mover of Men and Mountains*, we discover HIS-STORY of road construction equipment.

Figure 6. R. G. LeTourneau, mover of men and mountains.

The beginning of men moving mountains, was in 1885 in California where the first "tractor" was built. It was a steam engine that had large drive wheels with cleats on them. Diesel power soon replaced the boiler-fired steam engine. One of these monsters could do the work of 100 mules. But in poor soil, the cleated-wheels would spin and dig down under the weight of the tractor. In a rain-soaked field, Benjamin Holt was watching one of his tractors when the wheels started to spin and quickly dig down to the axles. In a flash of inspiration, he remembered treadmills — treadmills? — on which a horse would plod to turn the gears that ground the corn. Why couldn't a tractor, riding on a treadmill, spread the weight of the tractor on the soggy ground? It was a winner. The result was the new, 1905 model "tractor-on-a track" that crawled along over mud like a "caterpillar." "Caterpillars" suddenly appeared everywhere. Mules became dog food.

Then Europe became embroiled in World War I. The British Ministry, knowing about the "caterpillar," proceeded to armor-plate tractors and mount cannons on them. They called the monster a "tank". Quoting LeTourneau,

"It wallowed through water-filled shell holes, and crashed over sand bags to straddle German trenches. It knocked down stone walls and trees, crushed machine gun nests, and blew up ammunition dumps."

LeTourneau's story is wild, but there was little doubt as to the earth-moving possibilities for tracked "tractors."

The fresno was invented in Fresno. It was simply a big scoop shovel pulled by mules. The scoop shovel was 3 feet wide for a two-mule team, and 5 feet wide for a four-mule team. The operator, walking behind, manipulated the handle of the scoop shovel by raising it to load, and then by lowering it to drag the load. It was risky. Mule skinners reported gory accidents when the fresno hit a rock and flipped the operator up over the load. The fearsome handle was eliminated in 1915 by a scraper with a blade that could be raised and lowered by electric motors. The operator rode on the scraper. The scraper was pulled by a caterpillar. Coordination of the operators was troublesome — all of that "hollering" back and forth.

So, LeTourneau came up with the idea of a fully mechanized scraper mounted on a tractor and controlled by a single operator who could control the scraper by pushing buttons and levers. And LeTourneau expanded the scoop shovel into a box-shaped bucket with high sides that could handle larger quantities of soil. And he powered the tractor wheels with electric motors that smoothed out the pulling force.

The demand for moving large quantities of earth resulted in scrapers that were bigger and faster, and with a front panel on the bucket that could be dropped into place to prevent soil from spilling out during hauling. Speed was increased by lifting the bucket after it was loaded so it was not dragging, and by replacing tracks with high-speed rubber tires. This became the Tournapull in 1937. See Figure 7. It was the carry-all — the "mover of mountains."
In his autobiography, LeTourneau describes the bombing of Hickam Field during the attack on Pearl Harbor. The objective of the bombing was to destroy US air power in the Pacific. Quoting the ever-exuberant LeTourneau,

"Yet minutes after the attack, [Hickam Field] out lumbered a weird assortment of earth-moving machines, neglected by the enemy as a worthless target. Scrapers powered by Tournapulls filled in the bomb craters on the runways and aprons, packing and spreading the dirt so swiftly that the planes that had gone into the air to challenge the attackers, were able to return to their own base."

Figure 7. Tournapull – one of LeTourneau's inventions – became the carryall loader.

During World War II, earth-moving equipment was essential in construction of the Burma Road and Alcan Highway (1942). See Figure 8. And since then, earth-moving equipment has revolutionized construction of highways — and airfields, and mines, and dams, and railways. Excavation equipment has made practical the installation of buried pipes, culverts and tanks, and underground subways and traffic tunnels. Excavation Can-do makes possible underground homes, office complexes, and shopping malls.

Figure 8. Carry-all loaders during World-War II – on the Burma Road and the AlCan highway.

President Eisenhower's Highway Project of 1956 was conceived on the basis of culvert and drainage Know-how, and earth-handling Know-how. The Can-do was returning servicemen and American citizens of the Greatest Generation" who provided a disciplined, well-trained, and determined Can-do work force. The Interstate Highway System was born.

The “miracle of birth” of the Interstate System occurred 50 years ago. Could our Nation now give birth to such a miracle?   The future may, or may not, need another Interstate Highway System, but how about alternatives — like railways, subways, and buried pipes? The cost of transportation decreases from airways, to highways, to railways, to ships, and into pipes. The opportunities for innovation are unlimited if the Know-how is not expropriated, and if the Can-do is not squandered.

American Know-how- and Can-do can lead out toward a better world. But we can grasp the future about as far ahead as our memory of the past. Before the memory fades, let us remember the Interstate Highway Project of 1956 and the power of Know-how and Can-do.

Pipe-welding

The equipment for forming pipes from coils of sheet steel could not have happened except for advances in welding of seams and joints. So, to the story of welding;

Welding started in pressure vessels designed for steam engines. The first steam engine boilers were riveted. But rivets leaked at high pressures. Welding promised a leak-proof remedy. Temperatures were hot, pressures were enormous, and failures were catastrophic. Pressure vessel codes were conservative Welding in pipes and tanks was more recent. So, it was inevitable that welding standards for buried tanks and pipes would have been influenced by the older pressure vessel codes. But there are significant differences between high pressure vessels and pipes for successful transmission and distribution of water to — like 280 million people; and for buried tanks, like a million or two tanks buried under service stations in the USA.

Successful lap-welded tanks and pipes provide a large pool of information on the performance and performance limits of lap-welds. See Figure 9. Single-welded lap-welds are adequate in general. Double lap-welds are roughly ten percent stronger.

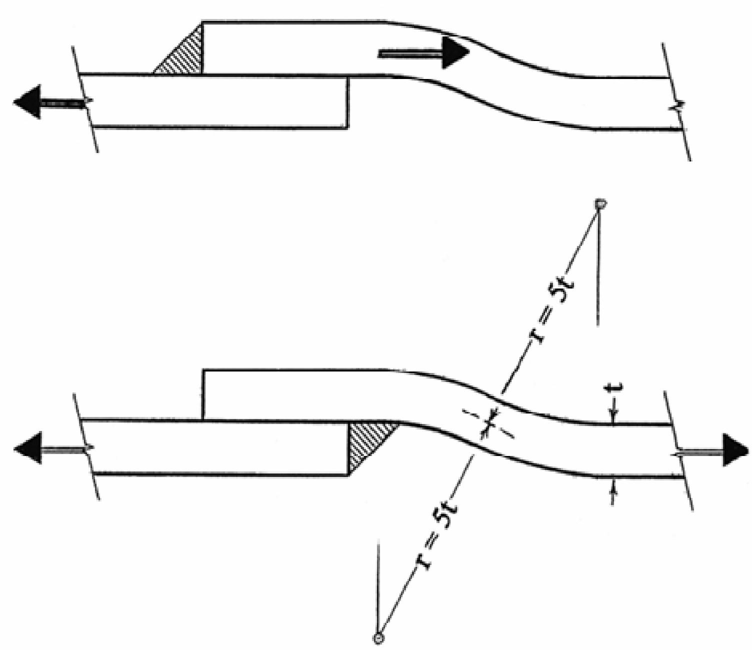


Figure 9. Single-welded lap joint (fillet weld) Outside weld (top) and inside weld (bottom) Double welded lap joint is both combined.

Before World War I, pressure vessels were riveted. They leaked at high pressures. Welding was a novelty that showed promise for sealing leaks — but only if the strength of the weld was adequate.

The authors of the ASME pressure vessel code reluctantly allowed welding, but only with large safety factors. From successful field experience, the American

Petroleum Institute prepared a code with less restrictive safety factors. In 1934 a joint API-ASME committee adopted a modified code, but controversy continued until 1951 when pressure codes merged into a single code which by 1968 became ASME Rules for Construction of Pressure Vessels.

Example (See Figure 10):
What is minimum wall thickness of a pressure vessel with joggle-joint welded joint?
From the pressure vessel code, an example of the ASME formula for wall thickness is

$t = PD/(2SE + 1.8P)$

where for example:
t = wall thickness
P = pressure = 100 psi
D = diameter = 48 inches
S = allowable stress = 21 ksi
E = weld efficiency = 55%.

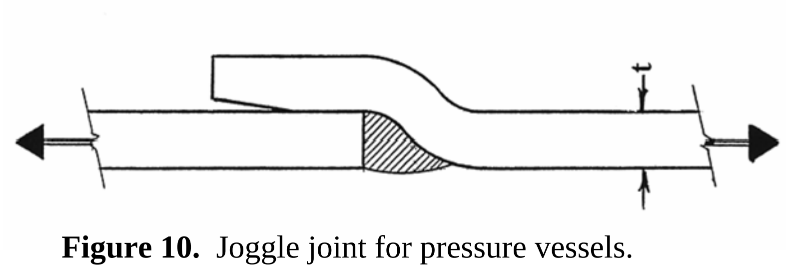
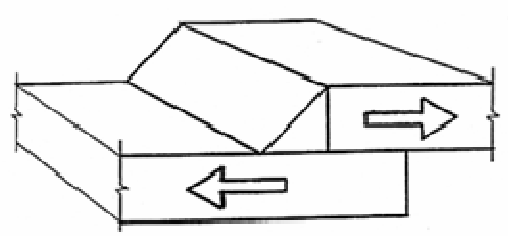
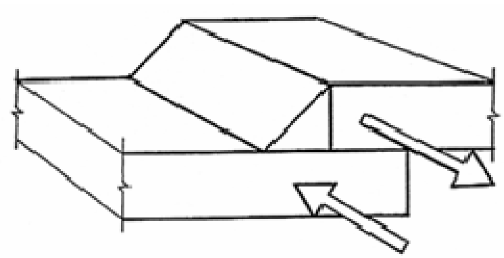


Figure 10. Joggle joint for pressure vessels.

Substituting values, wall thickness is $t = 0.208$ inch. Longitudinal stress is $PD/4t = 5.82$ ksi. But yield strength is 42 ksi. The safety factor is strength/stress = 7.2. Writers of the pressure vessel code were cautious because of many infamous boiler explosions at high pressures. But for pipes with low pressure, (like 100 psi), the pressure vessel formula is overly-conservative for buried steel tanks and pipes. And hoop stress is more critical than longitudinal stress on welded joints.
Moreover, the pressure vessel code is based on force parallel to the weld. In lap-welded joints, the force is perpendicular to the weld. From tests and from analytical theories, the perpendicular weld is 1.5 times as strong as the parallel weld. See Figure 11.



Forces perpendicular to weld



Forces parallel to weld

Figure 11. Relationship of direction of forces to the direction of fillet welds on lap-welded joints.

From tests of full pipe sections, longitudinal strength of the single-welded lap-joint is 75% as strong as the cylinder wall. Longitudinal stress is usually no greater than half of the hoop stress.

<u>Field experiences that made history</u>
Experiences from the field have made history. A typical example is leaks in welds in buried

gasoline storage tanks owned by the Church Universal and Triumphant.

Elizabeth Clare Prophet was the charismatic leader of the Church. Wealthy widows had been converted under the assurance of resurrection in the lap of the Lord if they would consecrate all of all of their worldly wealth to the Church. Then came the prediction from on high that the "Great and dreadful day of the Lord," was coming soon. The elect would be saved, and the Earth would be cleansed by fire. It was essential that the "elect" protect themselves against the onslaught of frenzied infidels who would attempt to invade the enclave of the elect on that terrible day. The remedy for the elect was to arm themselves, and to go underground. They purchased a beautiful canyon, Mol Heron creek, from Randolph Hearst on the boundary of Yellowstone Park. There they buried steel pipes, 14 ft in diameter which, like submarines, were fitted to sustain lives of 1200 of the most elect. But they needed fuel. They purchased 35 steel tanks, 9 ft diameter and 42 ft long, for storage of fuel — oil for heat, and gasoline for power. The tanks were to be buried uphill from the living units. That was late in the fall of 1990. Excavation for the tanks was proceeding in partially frozen soil. Then came the Word of the Lord. His coming was to be in April of the following spring (1991). Burial and filling of tanks suddenly became urgent. Backfill soil was bulldozed over the tanks with no attempt to compact the soil.
Early in the spring, a fisherman on the Yellowstone River near the confluence of Mol Heron Creek, smelled gasoline. He reported to the Montana State officials. The Church was ordered to remove the tanks. The Prophet was instructed by the Lord to seek compensation for replacement by suing the tank manufacturer. This required a determination of the cause of the leaks. As the loose soil, much of it frozen, began to thaw in the spring, the backfill soil settled and drug down the tanks. The tanks squatted. Flat spots developed on the bottoms. The flattened welds opened — and leaked.

Some of what has been learned from the history of tank and pipe leaks, is the need for care in backfilling. The pipe or tank must be held in shape. During installation, "It's the soil stupid."

In Saint Louis, circa 1970, a six-foot diameter, buried steel water pipe burst. The result was a geyser that blew open a 100 foot diameter crater. Water supply was "out-of-service" for much of the city. The pipe was designed for test pressures of 150 psi. The design was precise and correct. Explanations were in demand. The failure occurred on Christmas eve during a TV commercial when everybody ran to the bathroom, flushed the toilet, and took a drink of water. Suddenly water flow was enormous. Then everybody shut off the water. The result was a water hammer in the pipeline that developed a pressure many times greater than the 150 psi design pressure.

And so, from history, the precision of structural analysis is questioned. Design for strength of materials may be precise to three significant figures, but assumed pressure may not be as precise – nor is the soil pressure, or the deformations of the pipe, or the dynamics. But we are learning.

We are still making history, all of which portends an expanding future for buried steel pipes and tanks. Let us pay attention to the history in order to plan well for the future.