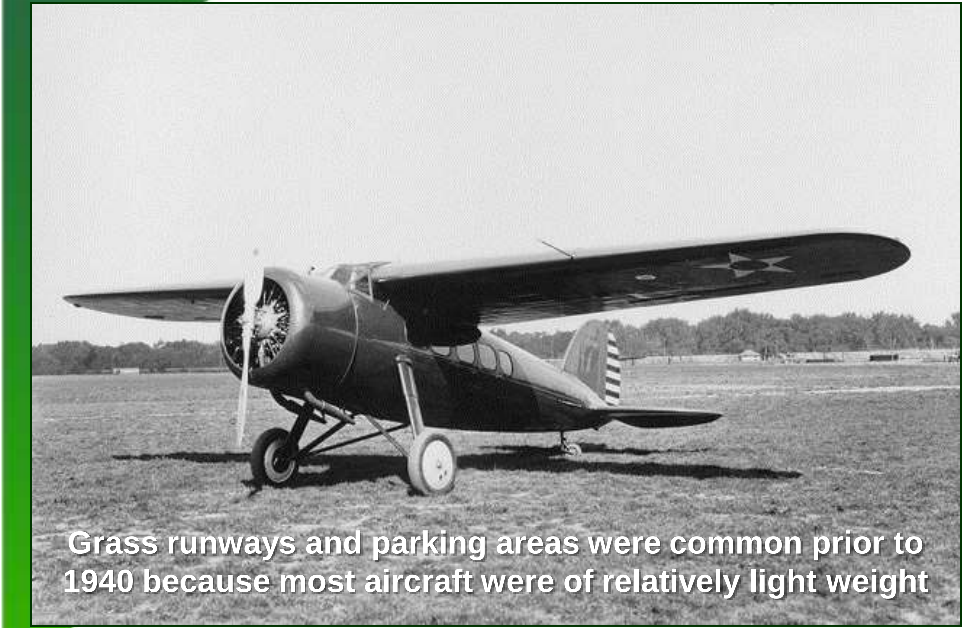
Part 3

COMPACTION TESTS evolved to support bomber loads on runways

Need to increase bearing capacity



Grass runways and parking areas were common prior to 1940 because most aircraft were of relatively light weight

The Boeing XB-15 bomber at Wright Field near Dayton, Ohio in 1937

- **Up through the mid-1930s military aircraft were relatively light, and could be supported on natural fields with grass runways, like that shown at upper left**
- **In 1937 the Army Air Corps began flight testing new long range bombers, like the Boeing XB-15, at lower left.**
- **This aircraft had a gross takeoff weight of 71,000 lbs, spread on tandem main gear tires and a single tail wheel. It could only use select concrete runways.**
- **Prior to this time, 12,500 lbs were the heaviest wheel loads any runway had been designed to handle**

The airfield runway crisis of 1941

- The massive **Douglas B-19 bomber** had a wingspan of 212 feet with a maximum gross weight of 162,000 lbs, spread onto just three tires. Its extreme weight engendered bearing failure of the concrete ramp at the Douglas factory in Santa Monica, forcing delays until a thicker concrete runway could be constructed.
- On June 27, 1941 the B-19 departed Clover Field in Santa Monica and landed at March Field near Riverside, California. Upon touchdown and taxi its massive 8-foot diameter tires inflicted noticeable damage to the taxiways and parking apron. This damage hastened an investigation by the Army Corps of Engineers, eventually leading to development of new design procedures to enhance compaction of pavement subgrades, which became the **Modified Proctor Compaction Test.**

Most bearing capacity failures occurred on taxiways in the European Theater

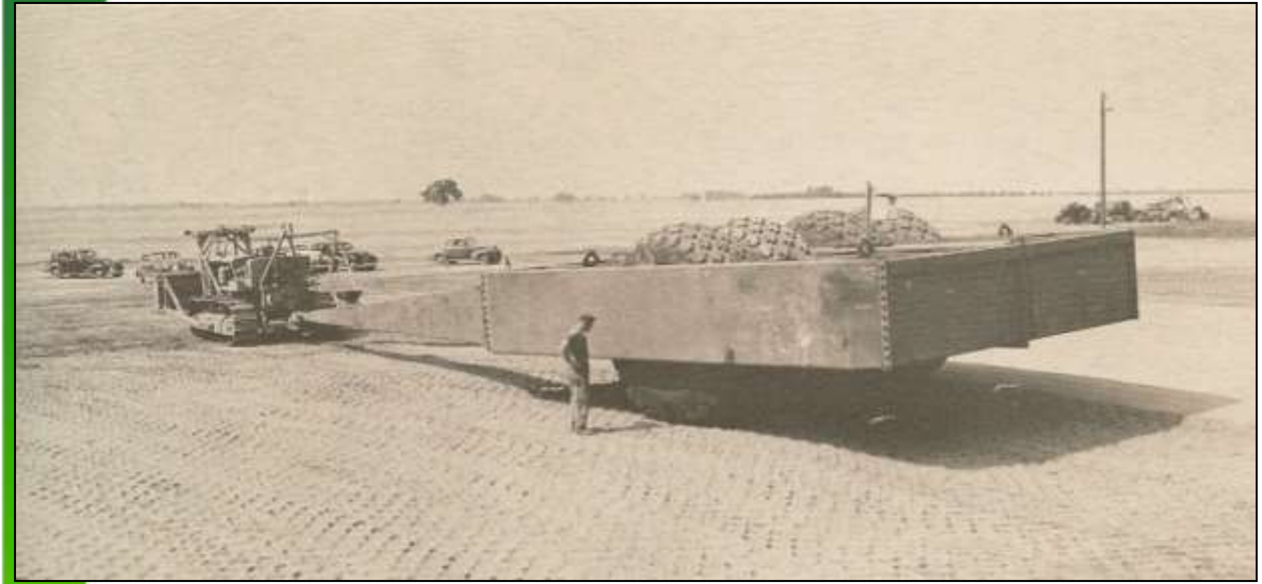
During World War II, the Corps of Engineers noted an increasing problem with pavement distress near the edges of heavily traveled taxiways. The weak link appeared to be subgrade preparation (images from 401st Bomb Group at Deenethorpe, UK)

The Corps of Engineers Airfield Pavement Design Advisory Council at the Stockton Test Track in California in 1944

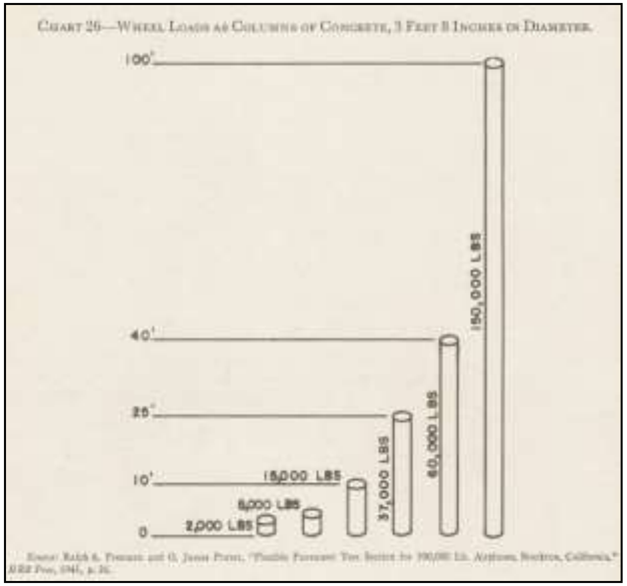
Army Corps of Engineers Airfield Pavement Design Advisory Council, standing on a B-19 bomber tire at the Stockton Test Track

Front row (left to right): Colonel Henry C. Wolfe (who had worked on the Fort Peck Dam soil mechanics problems), Prof. H.M. Westergaard of Harvard, and Dr. Philip C. Rutledge of Moran, Proctor, Freeman & Meuser. Back row, left to right: Prof. Arthur Casagrande of Harvard, Thomas A. Middlebrooks (the Corps senior expert in soil mechanics, who had also worked on the Fort Peck Dam landslide), James L. Land of the Alabama State Highway Department, and O. James Porter of the California Division of Highways, who originated the CBR test procedure, beginning in 1928.

Stockton Airfield Test Track



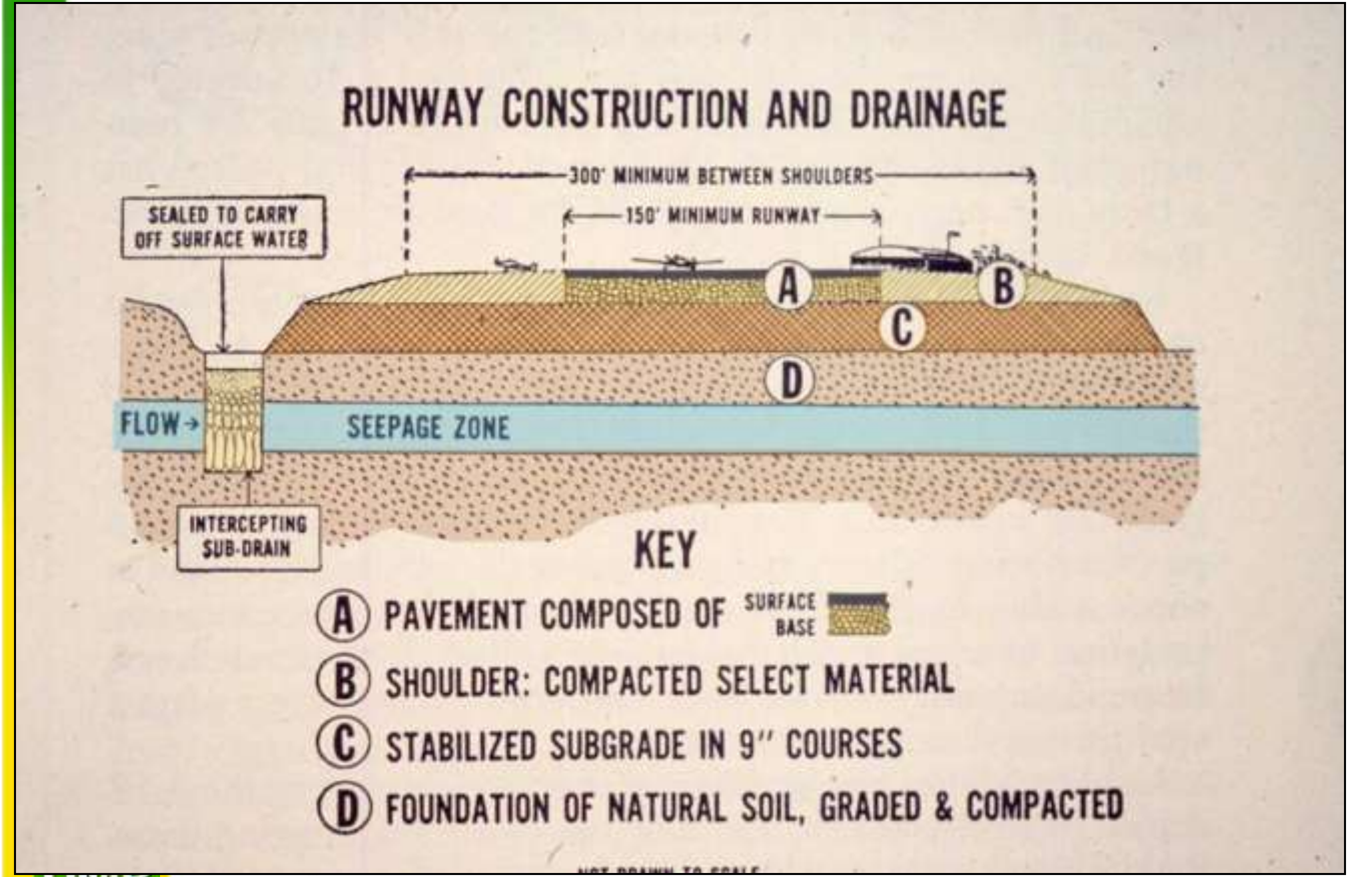
240,000 lb pneumatic roller used in the runway pavement tests at the Stockton Airfield test track



Aircraft wheel loads depicted as equivalent columns of concrete, three feet in diameter (from Freeman and Porter, 1945)

- **Stockton Airfield was the Corps' principal test site for evaluating Pappy Porter's California Bearing Ratio (CBR) test to compare subgrade modulus with various wheel loads and repetitions, working with the California Division of Highways and the Sacramento District of the Corps of Engineers under the supervision of Porter, between 1942-45.**

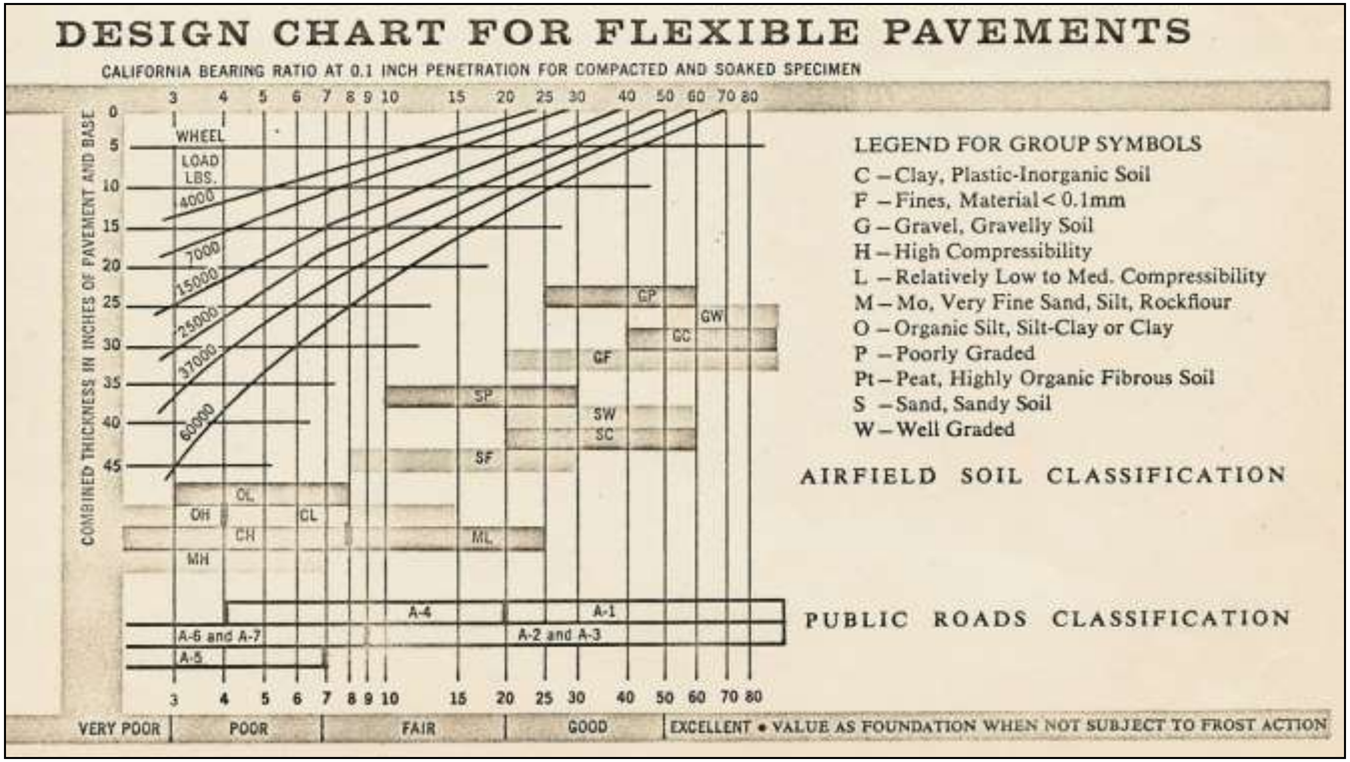
Standards for Army Air Corps Runway Design -1943



- Army Engineers developed credible standards that demanded mechanical compaction of subgrades and aggregate base courses

- **In 1945 the Army Corps of Engineers conducted numerous experiments with modified rollers, such as the railroad rail spike roller shown here. It engendered spike pressures of 260 psi empty, and up to 1080 psi when the roller was loaded with slurry, the case shown here.**
- **These were designed to evaluate rollers exerting 250, 450, and 750 psi; a 19,500-pound wobble-wheel roller; and 10,000-, 20,000-, and 40,000-pound rubber-tired wheel loads (simulating increasingly heavy bombers).**

The Corps of Engineers developed flexible pavement design procedures



- During the Second World War (1941-45) the Army Corps of Engineers developed specialized design procedures for flexible asphalt runways that incorporated the properties of the pavement subgrade, because the aircraft wheel loads are transmitted directly to the subgrade in flexible pavements. This focused attention on the importance of ***subgrade compaction***, leading to the **Modified Proctor compaction test** in 1946.
- These same design procedures were subsequently incorporated into post-war design of flexible asphalt highway pavements (as shown in the above chart), which Were used in the **Interstate & Defense Highway Program**, beginning in 1955.

Flexible Asphalt/Concrete and bituminous pavements

- Simplified flexible pavement design methods had an enormous impact on highway and airfield construction during the Second World War, leading to a post-war explosion in highway construction, beginning with the first Federal Aid to Secondary (FAS) highways program in 1944.

The Big Bomber

- With a maximum takeoff weight of 133,500 lbs, the **B-29 Superfortress** bomber required new pavement design methods and construction techniques at western Pacific bases
- In the fall of 1944 'Pappy' Porter was dispatched to the Mariana Islands to troubleshoot the pavement problems

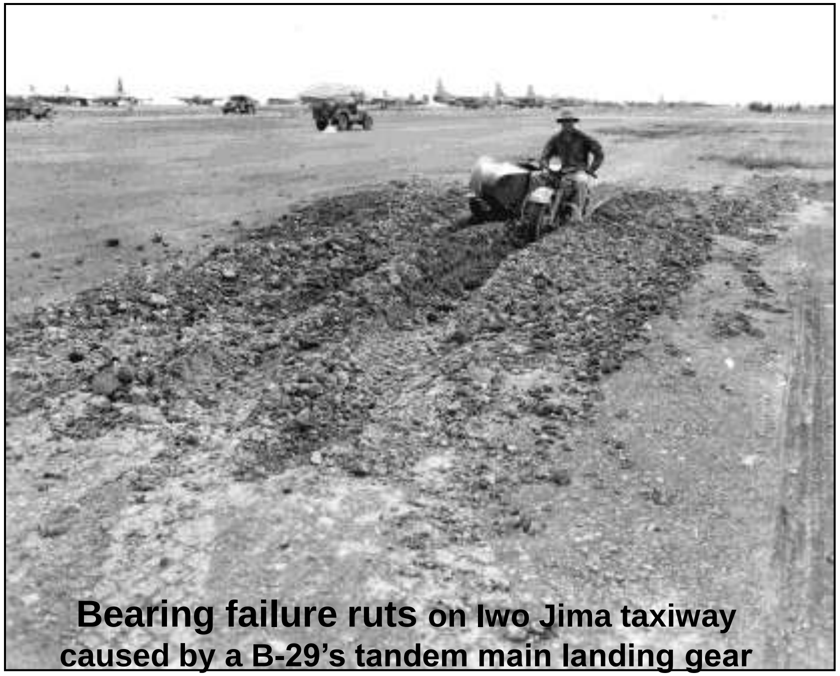
Bearing failures of B-29s in the Pacific Theater

B-29s queuing up on a taxiway at North Field, Tinian

The landing gear of the B-29 spread 133,500 lbs on six tires

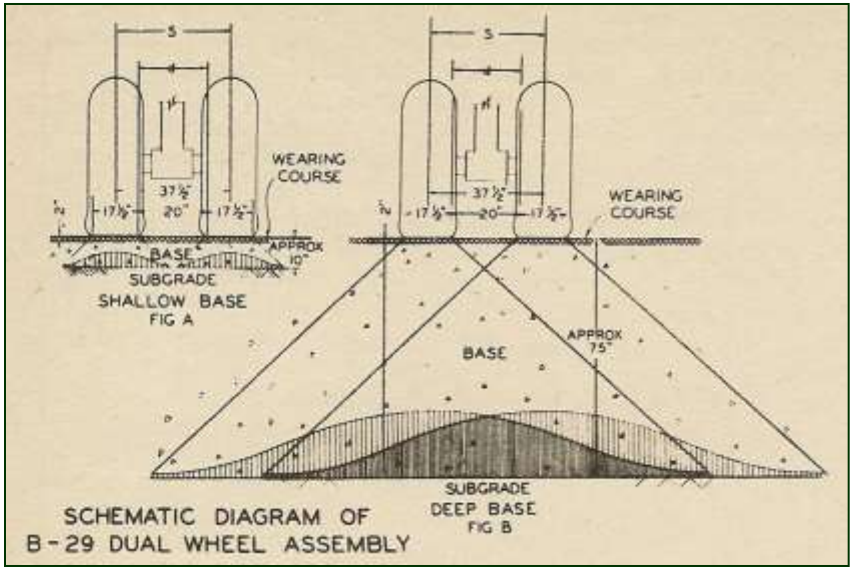
These images show B-29 bombers on taxiways in the Mariana Islands and Iwo Jima, where an unusually high degree of pavement distress occurred because of inadequate subgrade compaction. The volcanic cinders at Iwo Jima proved particularly problematic, as shown below.

Transient aircraft ramp at Iwo Jima, where bearing failures occurred, despite fact it was founded on 36 inches of volcanic cinder rock



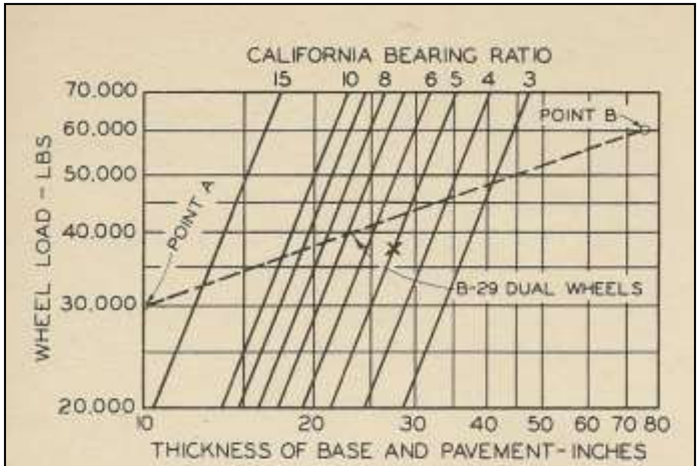
Bearing failure ruts on Iwo Jima taxiway caused by a B-29's tandem main landing gear

Solving the B-29 pavement design problem – focusing on subgrade compaction

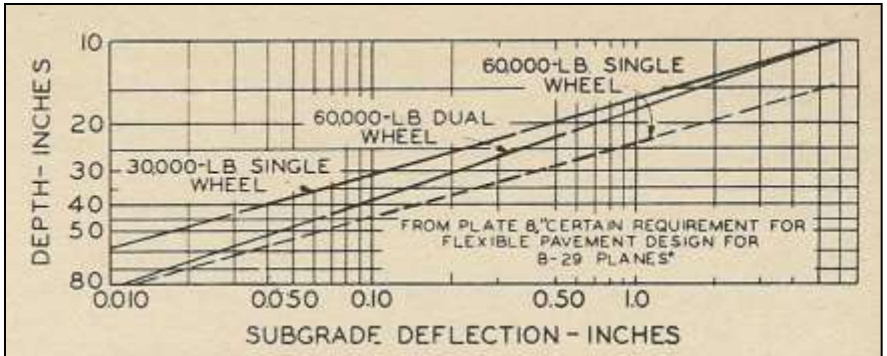


SCHEMATIC DIAGRAM OF B-29 DUAL WHEEL ASSEMBLY

Tandem main gear tires



DEVELOPMENT OF DESIGN CURVES-60,000 LB LOAD ON B-29 DUAL WHEELS



SUBGRADE DEFLECTIONS SINGLE VS DUAL WHEELS

Short hauls from quarry to placement on Iwo Jima

Compacting gravel subgrade for runways

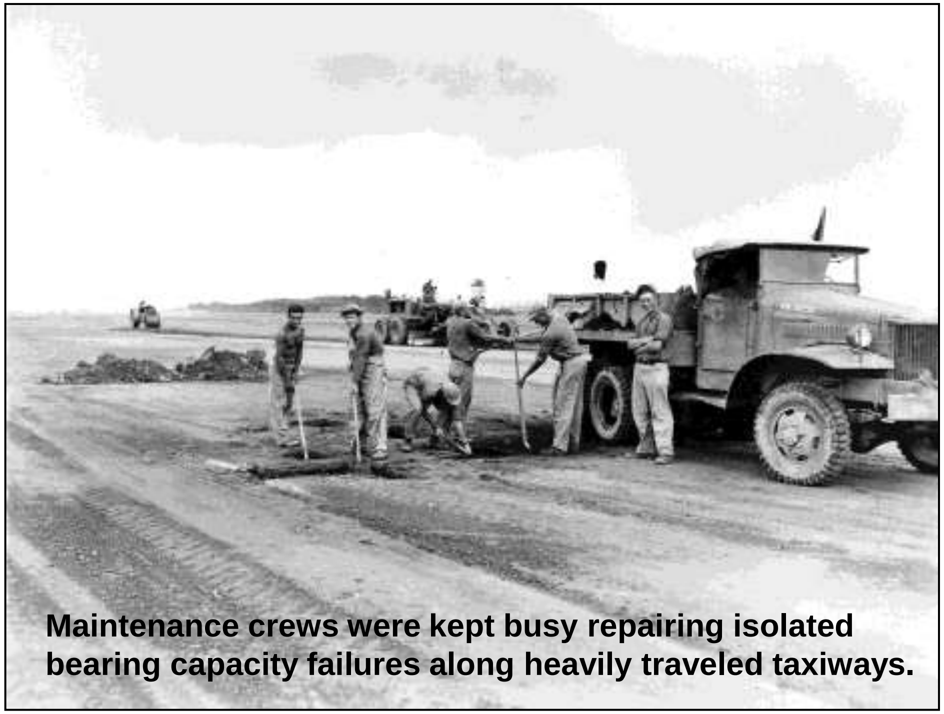
Spreading crushed coral topping for B-29 runways

Rolling crush coral pavement for B-29 runways


Laying and spreading 30-inch thick crushed coral topping layer in August 1945 at Yonton Field on Okinawa


By the war’s end in August 1945, Yonton Field on Okinawa was being constructed with a well-graded mix of crushed coral 30 inches thick!


54-inch thick B-29 hardstand at North Field on Tinian


Maintenance crews were kept busy repairing isolated bearing capacity failures along heavily traveled taxiways.

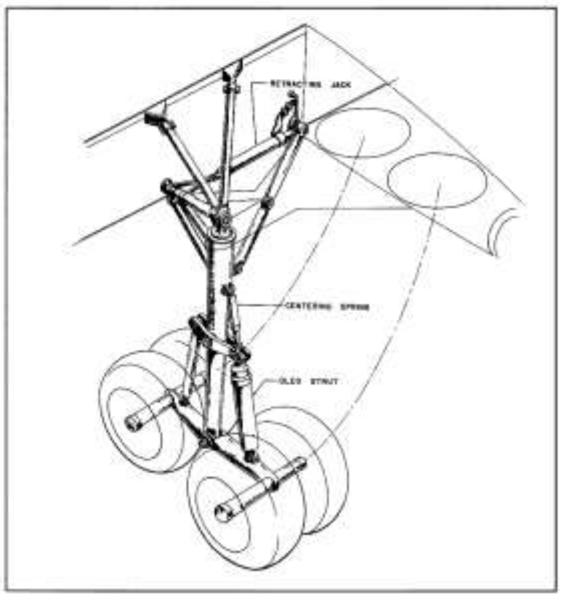
After the Second World War, the bombers kept getting larger

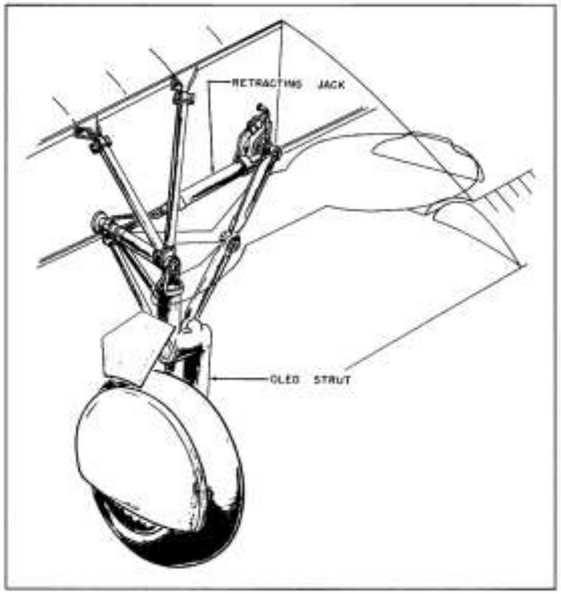
In 1952 the 10.4-megaton Ivy Mike hydrogen bomb was introduced, shown at left. It weighed 42,000 lbs, and the B-36 was the only aircraft that could carry it. This created another runway crisis…

Air Force officers looking over one of the 110-inch diameter tires of the YB-36

- **The massive 110-inch diameter wheels of the prototype Convair YB-36 bomber became the largest post-war pavement design problem, requiring pavement sections of 18 to 50 inches thickness, originally developed for the B-19. These subgrade materials were compacted to the new Modified Proctor standard.**

4-wheel tandem bogie undercarriage





- One aspect of the solution was to replace the massive 110-inch tires with a set of four 56-inch tires set in pair of 4-wheel tandem bogie undercarriages (landing gear); common to most heavy aircraft today

An unusual tracked landing gear configuration was among the many possibilities that were tested

The Modified Proctor Compaction Test (1946)

The Modified Proctor Test uses a 10-lb hammer in an 18-inch drop sleeve. Both the original and Modified Proctor test components are shown here

- The "modified Proctor basis" of 1946 was developed by the US Army Corps of Engineers Waterways Experiment Station in Vicksburg.
- It uses the same cylindrical mold as the Standard proctors (4 in. dia and 4.6 in. high, with a removable mold collar 2.5 in. high). The mold volume is 1/30th cubic foot
- A 10 pound hammer, 2 inches in diameter, was pulled upward and allowed to free-fall 18 inches, onto the soil (15 ft-lbs per blow)
- The soil was compacted in five lifts, with an average thickness of 0.80 inches/lift.

- 25 blows were exerted per lift, which equals 25 x 15 = 375 ft-lbs. The total input energy for the five lifts is 5 x 375 = 1875 ft-lbs on a soil sample with a volume of 1/30th cubic foot. This equals 56,250 ft-lbs of compactive energy per cubic foot of soil
- It was designated ASTM Test D1557 or Modified AASHTO T180, initially adopted in 1958

Pavement grooving along taxiway center lines because of concentrated wheel loads

Grooving was concentrated along painted taxiway centerlines

In 1955 a number of flexible pavement airfields supporting B-47 Stratojet bombers (shown here) were causing "grooving" of their taxiways along their painted center lines. Corps of Engineers researchers noted that the B-47 used a bicycle landing gear that applied two gear passes each time the plane taxied over the pavement. The practice of painting taxi-stripes for pilots to follow down the center of lanes narrowed the lateral wander of the bombers and concentrated wheel loads over very small areas.

- In 1954 WES-Vicksburg began a full-scale study of channelization, ultimately collecting data from twenty-three Air Force bases with 116 bituminous-surfaced facilities. B-47 load repetitions were also applied 6X that assumed in runway design because the plane enjoyed higher utilization than previous piston-engine aircraft.

Willard J. "Bill" Turnbull, PE (1903-97) received his BSCE from Nebraska in 1925 and became Chief Engineer of the Soils Division at the Waterways Experiment Station of the Corps of Engineers in 1941, where he played a major role in developing standards of practice for soil compaction and flexible pavement design over the succeeding decades, retiring in 1969.

- Construction of new 11,000 ft long bituminous asphalt concrete runways at Davis Monthan Air Force Base in 1953, to handle the concentrated wheel loads of the B-47 Stratojet.

Pavement Tests

The YB-52 was a giant leap in scale over the heaviest World War II bombers shown here next to it, a B-17 and B-50 (background).

- In 1955 the Corps of Engineers built this 258,000 lb roller to simulate the high wheel loads of the new jet powered bombers, the B-47 and B-52
- Air Force and Corps planners first responded by increasing pavement thickness requirements in ‘channelized areas’ by 25%.
- Further analysis revealed that pavement *channelization was more a product of densification of pavement and insufficient compaction* than of pavement thickness.
- Subsequent recommendations provided improved asphalt mix and compaction specifications.

B-52 wheel arrangement

- A B-52 weighs 172,740 lbs empty, and loaded, can weigh as much as 488,000 lbs
- Designers spread the bomber's weight over eight main gear tires (as opposed to only four on the B-47), grouping them four abreast (as shown at left), and using tire pressures of 260 psi

The B-52 was equipped with tandem gear that could be swiveled in to provide crabbing for cross-wind landings

Soil Runway Stabilization


C-130 dropping pallets using low altitude parachute extraction system during the siege of Khe Sanh in Vietnam


Re-grading ruts on earthen runway in forward operating area


Spraying RhinoSnot on rough graded runway for dust suppression


Dust cloud created by reversing turboprop engines on touchdown rollout

- Limited conflicts in remote locations like Southeast Asia exposed the need for dust suppression and soil stabilization techniques to handle tactical airlift loads, shown here.

Boeing 707-80 high flotation tire tests at Harper Dry Lake in the Mojave Desert in 1964. It was chosen because it is a “wet” dry lake, with a thin crust about an inch thick, above a soft silt bed. The aircraft’s tires sank about 6 inches (shown below).

This is why military transport aircraft are designed with much lighter wheel loads: to allow them to deploy on hastily constructed soil-cement runways in time of war. Runway constructed by the 864th Engineer Battalion in Operation Iraqi Freedom-2003.

- Above right: C-130 Hercules landing on a soil cement runway constructed by Army Engineers in Iraq in 2003.
- Above left: Landing tests using Boeing 707 on soft desert soils were carried out in 1964, by doubling the number of tires and reducing the tire pressure by 2/3, down to just 46 psi.
- These test were carried out when the C-5A military transport was being developed, to evaluate the military specification requiring the massive aircraft to be capable of landing on ‘soft graded surfaces.’

More pavement tests in mid 1960s

The Lockheed-Martin C-5B Galaxy has a maximum takeoff weight of 769,000 lbs, supported on 32 tires

- Upper left: 100,000 lb test carriage developed by the Corps of Engineers to simulate the wheel loads of a C-5A Galaxy, for pavement design
- The special tires on the simulator were 8 ft diameter and 3.5 ft wide
- Lower left: C-5's were originally equipped with 28 tires, using 128 psi air pressure on hard runways. In service the aircraft employs a tire pressure of 115 psi, considerably lower than other jumbo aircraft.
- The tire pressure can be reduced from inside to cockpit to accommodate landings on soft surfaces.

Highest Aircraft Tire Pressure

The highest aircraft or vehicle tire pressure ever employed in near-constant use was the supersonic **Lockheed SR-71 Blackbird**, which was capable of flying at speeds of Mach 3.2+. It had a maximum takeoff weight of 170,000 lbs distributed on eight 22-ply tires, impregnated with aluminum to protect them at high speed. The tires were inflated with nitrogen to a pressure between 415 and 425 psi. Even with all these precautions, the tires were only good for about 15 landings before needing to be changed out!