April 25, 1961 D. H. SEELY, JR 2,981,070

SEAL STRUCTURE FOR UNDERGROUND LIQUID STORAGE FACILITY

Filed Aug. 31, 1955 2 Sheets-Sheet 1

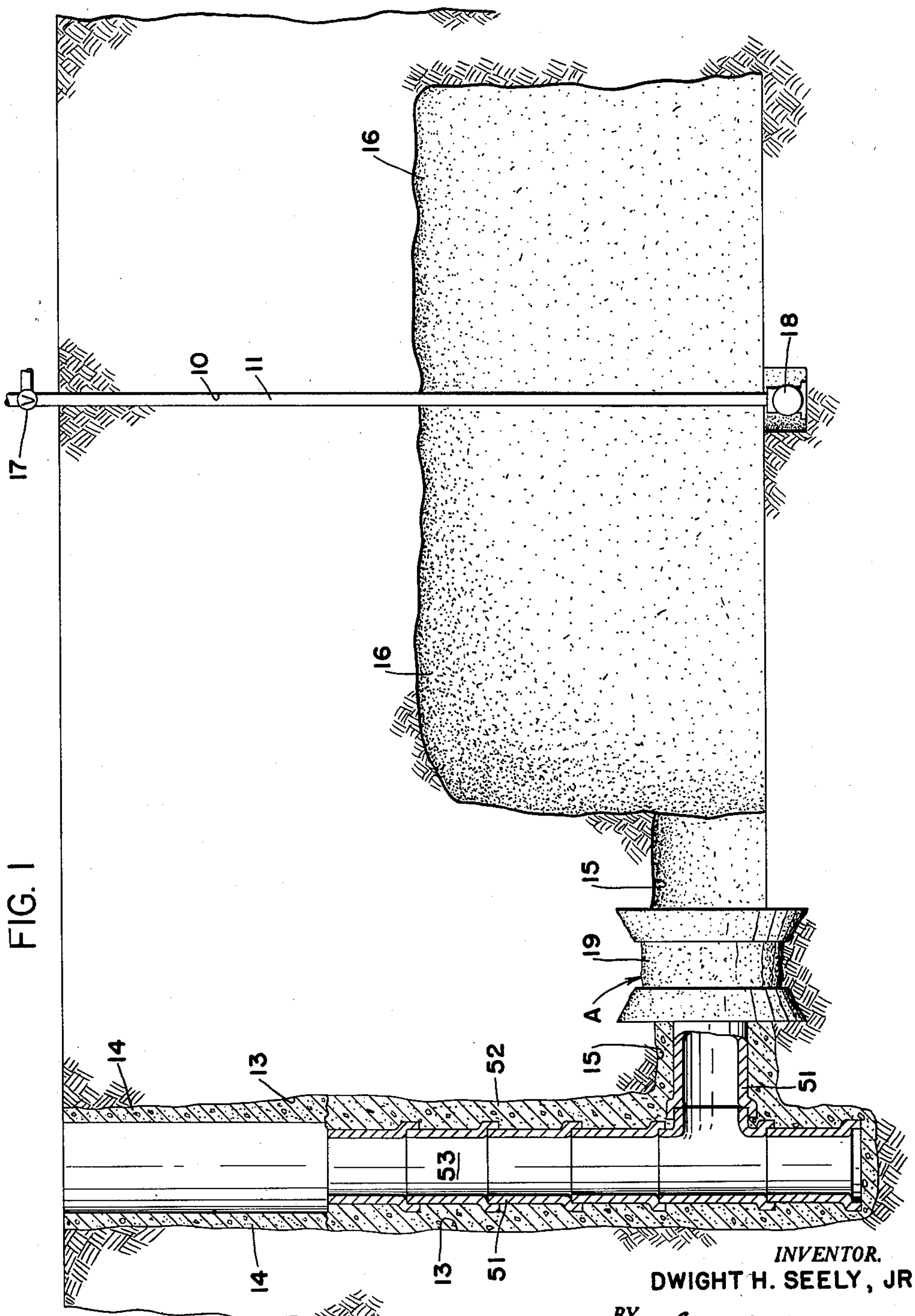

FIG. 1

INVENTOR.
DWIGHT H. SEELY, JR.

BY Leland L Chapman

ATTORNEY

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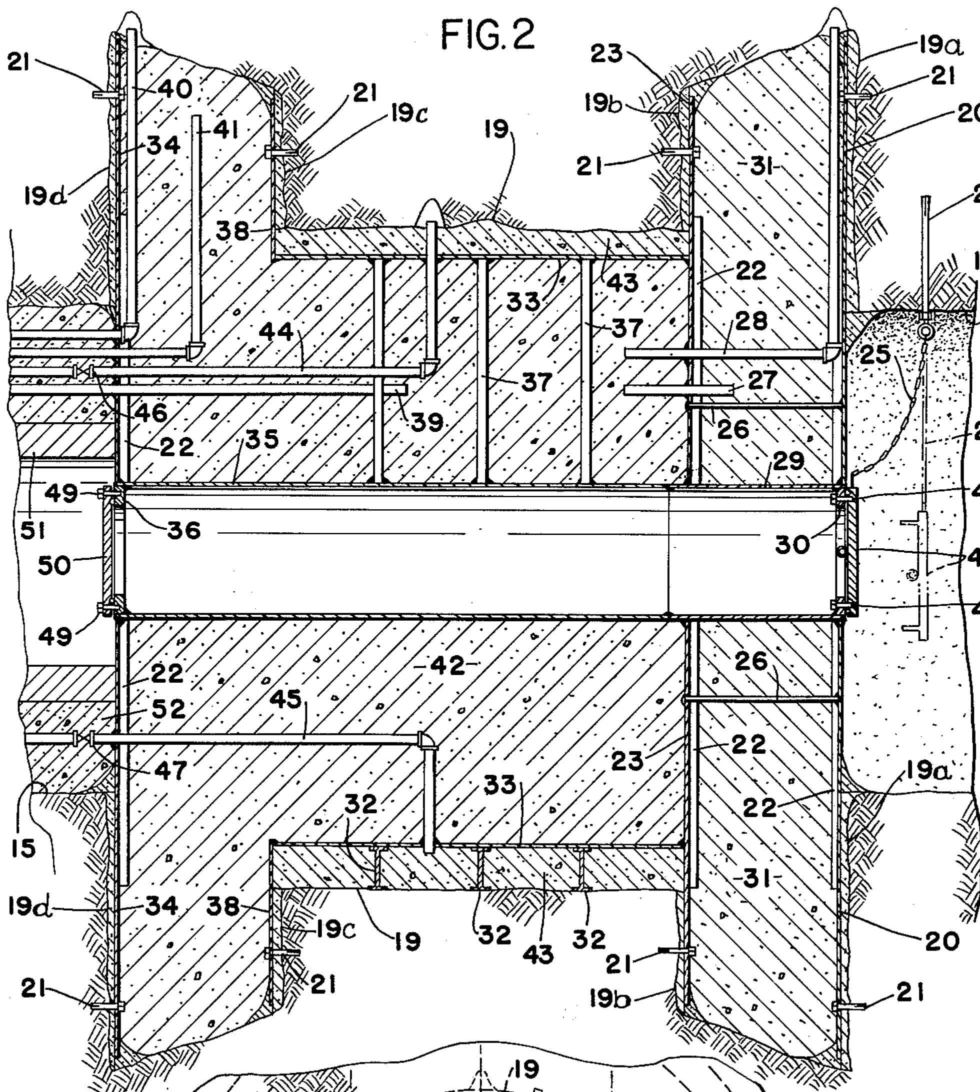
FIG. 2



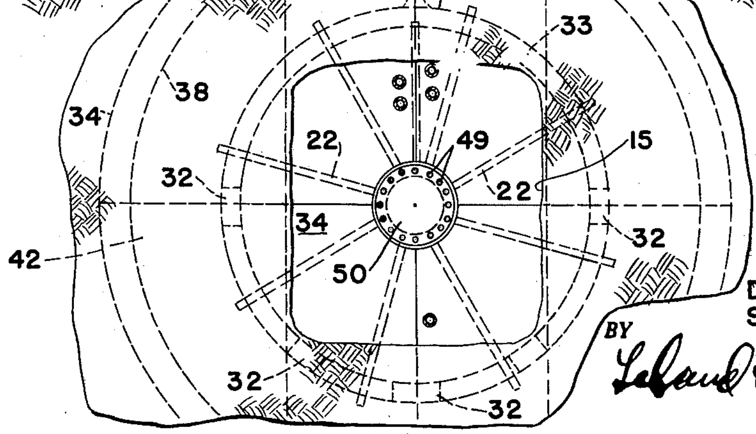


FIG. 3

INVENTOR.
DWIGHT H. SEELY, JR.

BY Leland L. Chapman

ATTORNEY

United States Patent Office

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SEAL STRUCTURE FOR UNDERGROUND LIQUID STORAGE FACILITY

Dwight H. Seely, Jr., Oklahoma City, Okla., assignor to Sohio Petroleum Company, Cleveland, Ohio, a corporation of Ohio

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3 Claims. (Cl. 61—.5)

The present invention relates to new and useful improvements in underground storage facilities. Particularly, it relates to improved sealing means for underground facilities used for the storage of liquids or gases under pressure.

Recent developments in the design and construction of storage facilities have led to extensive use of underground facilities for the storage of fluid products produced in the petroleum, chemical and petrochemical industries. It has been determined that underground facilities substantially reduce the amount of capital required heretofore to provide aboveground storage facilities. Underground facilities for storage of liquids or gases under pressure have been constructed in many places in this country. Generally, such facilities are of one or two types, the first type involving storage in underground salt domes and the second involving mined underground caverns. My invention relates particularly to improvements in the construction of underground facilities of the latter type.

In choosing a suitable underground stratum for the construction of a mined cavern, it is customary to drill one or more cores by conventional core drilling methods in the general location where the facility is to be installed. The cores obtained by such drilling make it possible to select a geological formation having the proper physical characteristics and located at the proper depth underground to serve as a storage cavern.

Of first consideration is the depth of the excavation to be used and this is determined by the geological information available concerning the ability of the overburden to retain pressure. For example, for a pressure of 100 pounds (gauge) an excavation or storage cavity should be located at least 100 feet below ground according to a rule of thumb published by the Natural Gasoline Association. This may be varied to some extent in cases where the roof formation is of sufficient strength to act as a confining medium as well as an overburden, such, for example, as solid limestone or solid granite.

It is also necessary that the storage cavity to be excacated have a roof stratum consisting of a formation which is impermeable, hard, and substantially free of fractures, and one having sufficient beam strength to support the necessary overburden. An example of a suitable formation for a roof structure would be massive limestone.

Of equal importance are the properties required for the walls of the excavation. The walls of the excavation should preferably be impermeable, reasonably dry and devoid of impurities or properties which might have a deleterious effect upon the liquid stored. A suitable formation for the cavern walls would be tight, sandy, shale to shaly sandstone and silty grey shale. This formation is dry, non-waterbearing, tight, and will not effect the stored materials. If such a formation is not available, a water-bearing formation may be employed as the stored material will displace the water.

It is desirable, although not necessary, that the cavern formation be followed immediately below by a hard formation suitable for a cavern floor, such, for example, as hard brittle limestone. However, if the walls of the cavity possess the desired properties, a special floor formation per se, is not required.

The foregoing information is generally known in the industries where such underground caverns have been employed as storage facilities. Underground caverns are usually constructed by conventional mining methods, e.g., a mine shaft may be first sunk to the desired depth and the cavern is then excavated.

The particular problem I have overcome is concerned with the sealing of the mine shaft with respect to the cavern. The object of my invention is to provide an impermeable seal between the mine shaft and the cavern to effectively preclude the escape of any of the material which is to be stored in the cavern.

Seals of the type contemplated herein may be disposed in any relative position, e.g., either vertical or horizontal. When it is desired to form one or more caverns by means of a common mine shaft, tunnels may be excavated in several directions from the mine shaft and a cavern may then be excavated at the terminus of each tunnel. In such a case, it will usually be more convenient to locate the seal structure in the tunnels extending from the mine shaft. Merely for the purposes of description, such a case is contemplated herein below.

There are several known methods by which such a tunnel could be sealed. For example, the tunnel leading from the cavern to the mine shaft may be filled and sealed with concrete or cement. Alternatively the tunnel could be sealed by means of an impervious plate embedded in the walls of the tunnel. In the underground storage of liquids at atmospheric or near atmospheric pressures, such methods have generally been found to be suitable. However, when liquids or gases are stored at superatmospheric pressure, such sealing methods are not wholly effective and lose utility. For example, in the case of the underground storage of liquefied petroleum gas, it has been found that cement is relatively porous to such a liquid and that a dangerous amount of the liquid will escape through the concrete no matter how thick it may be, creating a considerable safety hazard. Since underground caverns are generally located in shale formations and it is a characteristic of shale that it has a low shearing strength, the use of an impervious plate in such a tunnel is not considered a satisfactory solution to the problem.

If an impervious plate is employed, such as a metal plate embedded in the tunnel walls, there is considerable danger of a breaking away of the tunnel wall with consequent collapse of the seal. The tunnels are frequently ten feet or larger in diameter and consequently a metal plate inserted in the wall to seal the tunnel imposes a substantial shearing stress on the walls of the tunnel at pressures substantially above atmospheric pressure. Another drawback of this type of seal is that the stored material has a tendency to escape around the perimeter of the plate.

I have now invented a seal structure for underground storage facilities which effectively overcomes the defects inherent in the sealing means of the prior art.

In brief, the seal structure of my invention comprises an impervious mass embedded in the walls of the section to be sealed having a cross-sectional area greater than the area of that section. The structure may also have provision for access therethrough.

As the incompressible material which is used in connection with the seal structure, I prefer to employ concrete. However, in the case of a seal structure of considerable size, the heat generated during the setting of the concrete may cause difficulties. In such a case, it may be desirable to use crushed rock, bound together by a mixture of water and cement as the incompressible material.

The invention will be better understood by reference to the accompanying drawing wherein similar figures denote similar parts throughout, and in which:

Figure 1 is a diagrammatic cross-sectional view cut through the center of the underground cavern, mine shaft and the tunnel connecting the cavern to the mine shaft;

Figure 2 is an expanded cross-sectional detail view of the seal structure of this invention;

Figure 3 is a front view of the seal structure looking down the tunnel from the mine shaft prior to installation of the tile.

Referring now to Figure 1, the construction of the underground cavern will first be described. Ordinarily, the first step in the construction is to drill a hole **10** to the desired depth of the proposed cavern floor. This hole may be formed in the preliminary coring operation.

The next step in the construction of the cavern is the excavation of a mine shaft **13**. The mine shaft may be provided for part or all of its length with a suitable casing **14** such as a concrete wall, if necessary. A tunnel **15** is then excavated perpendicularly to the mine shaft **13**. Depending upon the number of caverns desired, one or more tunnels such as **15** may be connected to the same mine shaft. When the approximate area is reached by the tunnel **15** where it is desired to construct the cavern, the main excavation takes place and the cavern **16** is constructed. The diggings from the cavern **16** are removed through the tunnel **15** and the mine shaft **13**. The excavation is accomplished by the usual mining techniques.

The cavern **16** may take various shapes insofar as the profile of its wall structure is concerned, depending upon the nature of the formation of the stratum and giving due consideration to the most economical method of excavation. For example, if the substance of the cavern walls has no tendency to slough or cave in, the walls may be substantially vertical as shown by the profile of Figure 1. On the other hand, in a stratum of dense shale or silty grey shale where there is a likelihood of sloughing, the cavern is excavated with sloping sides to obviate this fault. When the cavern is complete, appropriate connections between the hole **10** and the cavern **16** are made to provide for the ingress and egress of the liquid to be stored. These will include the valve means **17**, a string of pipe **11** and a pump **18** which are known in the art and are not a part of my invention. The tunnel **15** connecting the cavern **16** to the mine shaft **13** must be sealed to prevent the escape of the stored liquid or gas from the cavern **16**.

The seal structure A of this invention is shown on Figure 1 in cross-section but the manner of construction of the seal structure can be better understood by reference to the expanded view shown in Figure 2 and referred to now.

The first step in constructing the seal structure A of this invention is to excavate a recess **19** in the wall of the tunnel **15**. This excavation can be conveniently accomplished by means of hand operated pneumatic rock chisels and drills. When the excavation of the recess **19** is completed, the surface of the recess may desirably be coated with a sealing compound to seal any voids or crevices therein. As a sealing compound, it may be desirable to employ a compound which is impervious to the material to be stored in the cavern. In some instances it may also be desirable to support the roof of the recess **19** by means of roof support jacks (not shown). All surfaces of the recess **19** which are to be in contact with metal should be made as smooth as possible.

Before proceeding with the construction of the seal structure, a bolt **24** should be set into the roof of the tunnel **15** a short distance from the cavern face of the recess **19**. A ring and chain **25** are welded to the bolt **24** for a purpose which will be described hereinafter.

The next step in the construction of the seal structure is to construct a plate **20** adjacent to the wall **19*a*** of the recess **19**. This plate **20** is desirably constructed from a number of pre-formed sections which are assembled in situ by a seal welding or other suitable means. The thickness of the plate **20** need not be great and in the present instance a thickness of ¼″ was found to be suitable. For the purpose of providing structural support, stiffeners such as angle bars **22** may be welded to the plate **20**. Plate **20** is held against the wall **19*a*** by means of the expansion bolts **21**. Void spaces between the recess wall **19*a*** and the plate **20** may be filled with cement or other sealing material.

In order to complete the cavern side bulk head, a plate **23** is constructed adjacent recess wall **19*b***. This plate is similar to the plate **20** and is constructed in a like manner. Expansion bolts **21** hold the plate adjacent to the wall **19*b***. When plate **23** is finally assembled, a number of reinforcing spacer rods **26** are welded to the plates **20** and **23**. A cement fill pipe **27** and an air vent pipe **28** are then installed communicating with the area between plates **23** and **20**. A conduit **29** which will be used as a manway is then welded to the plates **23** and **20** in an area provided in the plates **20** and **23** at the time of construction. The section **29** has a flange **30** on the cavern side.

The area **31** between the plates **20** and **23** is filled with an incompressible material such as cement through the fill pipe **27**. If cement is employed to fill the space **31**, the high heat of hydration of cement may render it impractical to completely fill the space **31** in a single dump. If such is the case, several dumps can be spaced at suitable intervals. The last dump should be continued until material begins to come out through the vent pipe **28**.

The next step in the construction of the seal involves the center section. I beams **32** are placed on the floor of the recess **19** and these beams support a center cylinder form **33**. The center cylinder form **33** is assembled by welding or other suitable means from a number of pre-formed sections. The center cylinder form **33** should preferably be as nearly circular as is practicable, but it is not necessary that it be perfectly circular.

When the center cylinder form **33** has been assembled and has been welded to the plate **23**, the shaft end form plate **34** is constructed in the same manner as plates **20** and **23** but several sections of this plate are left out for later insertion for reasons that will become apparent hereinafter. The plate **34** is held against the recess wall **19*d*** by the expansion bolts **21**. Plate **34** has stiffeners **22** welded to its face.

The conduit section **35** is installed and welded to conduit section **29** and plate **34**. Conduit section **35** has a flange **36** at its shaft end. Stiffeners **37** may be welded to the top side of the conduit section **35** and to the roof of the center cylinder form **33**.

Ring form **38** is assembled adjacent to the wall **19*c***. This form is constructed in a manner similar to that employed in the construction of plate **34** and is held in place by means of the expansion bolts **21**. The ring form **38** is welded to the outer edge of the center cylinder form **33**.

The fill pipe **39** and the vent pipes **40** and **41** are now installed. Vent pipe **44** is installed in the squeeze void **43** and a fill pipe **45** is also installed to service the void **43**. The remaining sections of plate **34** are now installed. Concrete or like material may now be dumped into the void space **42** within the center cylinder form **33** through the fill pipe **39**. Once again, because of the heat of hydration of such materials, it will probably be necessary to fill the space **42** by dumping the concrete or like material in small amounts at suitable intervals.

When the center void space **42** is completely filled with concrete, a suitable interval for the complete setting of this material should be allowed. When this interval has elapsed, the void space 43 should be filled and maintained under a high pressure with a cement which is impervious to the material to be stored and which is capable of forming a tight bond with the surrounding stratum. The cement should preferably contain an additive, many of which are known to the art, which will prevent its shrinkage upon setting. The filling is accomplished by pumping a mixture of this cement under a high pressure through the fill line 45. The pumping is continued until the special cement begins to discharge through the vent line 44. When the cement begins to flow out of the vent line 44, the valve 46 should be closed and pumping continued until the pressure within the squeeze void 43 is at least 300 lbs. per square inch and preferably somewhat higher. When this pressure is attained, the valve 47 in the fill line is closed.

As the last step in completing the construction of the seal, the cavern side manway blind flange 48 is secured to the flange 30 by means of bolts 49. In order to hold the blind flange 48 in position while securing it to the flange 30, it will be necessary to employ the chain 25 heretofore mentioned by securing it to the flange 48. The seal is completed by installation of the shaft side manway blind flange 50 which is secured to the flange 36 by means of bolts 49. The blind flanges 48 and 50 are sealed by appropriate gaskets (not shown).

When the seal has been completed, a tile or pipe 51 is laid from the shaft side of the sealed structure part way up the shaft 13. The area 52 around the tile 51 is filled to a level above the highest point within the cavern with concrete or a mixture of crushed rock and concrete so that the seal structure will be subjected to a compressive stress. As a final precaution, the area 53 shown on Figure 1 within the tile may be filled with water.

Figure 3 of the patent drawing shows the various parts of the sealed structure looking from the shaft 13 towards the cavern 16. The important feature to be noted in this figure is that all of the main structural elements of the seal structure have a diameter larger than the diameter of the tunnel 15. It is this feature of the seal structure which makes it particularly useful as the stress imposed on the surrounding stratum is largely compressive in nature rather than shearing.

It will be obvious to those skilled in the art that modifications of the particular sealing means disclosed may be made. However, it is intended to cover all such modifications of the invention as would reasonably fall within the scope of the appended claims.

I claim:

1. In combination with an underground storage cavern, a passage communicating with the cavern having a pair of spaced-part lateral enlargements in the wall thereof forming continuous trenches of appreciable depth and limited axial extent in the material bounding the passage, the side walls of said trenches being substantially normal to the axis of the passage and the extent of the latter between the trenches also being enlarged with respect to the normal cross-section of the passage but to a lesser extent than the trenches, a pair of metal bulkheads of considerably larger area than the passage disposed in one of said trenches with their peripheral portions respectively against the side walls of said one trench, whereby said bulkheads extend in substantially parallel axially spaced relation transversely of the passage and substantially into the boundary material beyond the wall of the passage, a first mass of substantially incompressible set material completely filling said one trench between the peripheral portions of the bulkheads therein and against the bottom of the trench, said first mass further extending inwardly between the bulkheads well beyond the thus embedded peripheral portions of the same, a second mass of substantially incompressible material extending along the wall of the passage between the two trenches and filling the other of said trenches, the second mass also extending inwardly over the length thereof well beyond the portions thereof embedded in the boundary material between the trenches and in said other trench, said pair of metal bulkheads and first and second masses of substantially incompressible material together forming an embedded seal structure of general spool shape in the passage, and sealing compound disposed under substantial pressure between the outer periphery of the intermediate portion of said structure, between the relatively enlarged ends thereof defined by the trenches, and the boundary material surrounding said intermediate portion to form a tight bond therewith.

2. The combination set forth in claim 1 wherein the intermediate portion of the seal structure between the enlarged ends thereof is enclosed by a continuous metal liner, and the sealing compound under pressure is between said liner and the surrounding boundary material.

3. The combination set forth in claim 2 wherein one end of said liner is disposed against the inboard bulkhead of the pair of the same in said one trench, the other end of the liner is approximately in the plane of the inboard side wall of said other trench, a metal flange section extends outwardly from about said other end of the liner into said other trench against the inboard side wall thereof, and a further metal bulkhead of considerably larger area than the cross-section of the tunnel is disposed in the other trench against the outboard side wall of the same, that portion of the second incompressible mass filling said other trench being between said metal flange section and further bulkhead therein.

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