Combatting crisis with composites

Dr Oleg Sukovoy, SPS Technology, UK, champions the use of composite repairs to extend the lives of storage tanks.

In recent months it has become commonplace to say that COVID-19 has had an unprecedented impact on global industry, with the oil market among those left grappling with the most acute challenges. The sudden and deep drop in demand and price following the outset of the pandemic and the untimely Saudi-Russia price war resulted in historic market shocks. Most devastatingly, in April 2020, the WTI oil price fell below zero, with negative index in the WTI futures.

The circumstances tested tank storage capacity in a way almost never seen before, with some producers paying up to US$40/bbl for their product to be taken into storage. Indeed, at the time, storage was in such short demand that previously unthinkable concepts were placed on the table as genuine solutions to the problem. For example, on 11 May, the *Wall Street Journal* reported that "would-be investors were looking to stock it away in giant pools, caves or anywhere else."[1]

While the worst-case scenario of overwhelmed storage capacity did not become a reality, the oil amassed in storage remains substantial – meaning owners of aboveground storage tanks must continue to respond with measures to manage the crisis. Critically, this includes taking steps to ensure the smooth operation of their facilities for uninterrupted supply.

The continued demand pressures make any shutdown of assets for essential maintenance acutely undesirable, with owners looking to avoid time out of service for these facilities at all costs using a range of temporary solutions. However, there is a permanent steel repair solution with no hot work and, critically, no time out of service available: a steel-elastomer-steel composite, known as SPS, designed by SPS Technology.

Table 1. Key material characteristics

Item	Description
Compression	Can withstand a compressive force of over 1000 t/m^2 between -60˚C and 100˚C
Impact	Highly impact resistant. It is routinely used to upgrade large bulk carrier tank tops that are regularly subjected to 50 t grab discharge operations
Flexure	The elastomer core has a much lower elastic modulus than steel, making it more flexible and less prone to fatigue damage. SPS structures in the marine environment are subject to continuous bending and flexing from sea motions
Permeability and chemical resistance	Tests have demonstrated that the elastomer core is impermeable to hydrocarbons, cannot absorb any chemical without volume change, and will not degrade, react with, nor contaminate the chemical

A new failsafe approach

This composite is routinely used for both civil and maritime applications to reinstate and upgrade existing steel structures, often for the most demanding of applications. It has been applied successfully to rehabilitate and strengthen structures that have degraded over time or require strengthening to increase operational capability. Originally, the design and construction processes were developed on ships and offshore structures, though the principles are generic and therefore applicable to storage tanks of all shapes and sizes, underground or aboveground, delivering protection against tank leakage; a new tank boundary (floor, shell or roof) that can be readily monitored without risk of corrosion; a safe, fast and straightforward installation procedure; as well as a strong, long-lasting tank structure.

The composite provides benefits in fabrication economics, structural performance, safety and environmental protection for a broad range of applications in maritime, civil and defence industries. It can be used for new construction and also in ship/offshore repairs and strengthening, as illustrated in Figure 1, where new top plates are structurally bonded to the existing stiffened plate structure. This process saves significant time and cost by allowing the existing structure and any services attached to it to remain in place while the strength and stiffness are restored or increased as required.

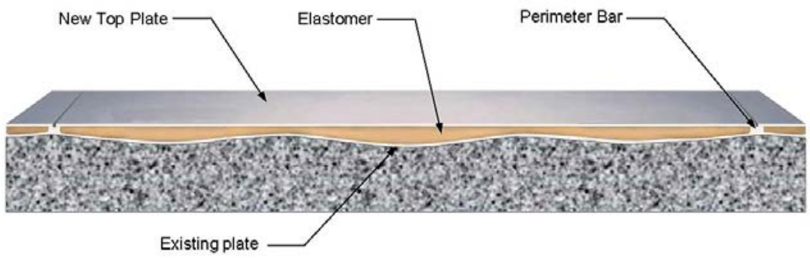

Figure 1. SPS section (storage tank floor application example).

Extensive development and testing

This steel-elastomer-steel composite technology was developed in close collaboration with BASF AG in the late 1990s and with guidance from the major classification societies and regulatory authorities. Physical properties, design parameters, and production techniques have been established through extensive analytical, experimental and prototype work. SPS is a fully class approved, permanent repair technology used extensively within the maritime industry.

Transferring the same high safety and quality standards to the storage tanks market could offer an excellent alternative repair solution with substantial benefits for owners and operators. The benefits include schedule savings of up to 75% (based on experience of similar scale maritime projects) and cost savings in the order of 20%. For roof repairs, the technology can be installed using a no hot work method,

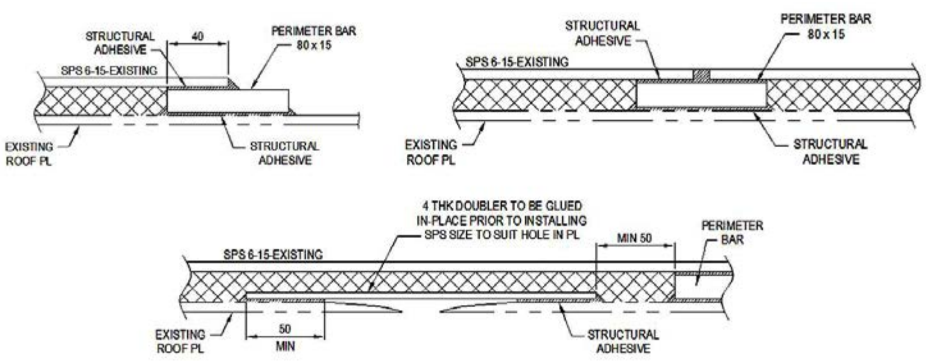

Figure 2. SPS repair details.

Figure 3. Oil storage tank P-770B: SPS no hot work repair.

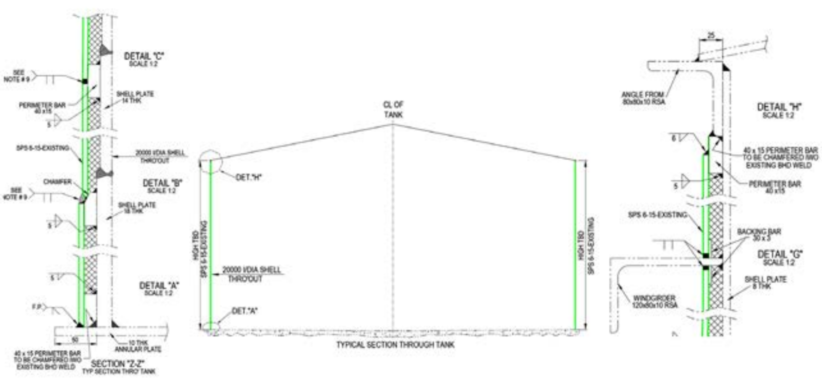

Figure 4. SPS reinstatement of the shell plating.

allowing the tank to remain in operation while the repair is completed. Once installed, the composite provides a triple barrier (steel-elastomer-steel) to the tank, thereby mitigating the likelihood of potential future leakage. The technology can also be used as an alternative to install a double floor, tank jacking or fitting a glass reinforced plastic/polyester (GRP) liner for secondary containment.

The composite structural plate comprises two metal faceplates (any grade steel, stainless steel, aluminium or other metal) bonded with a solid compact elastomer core. The elastomer core provides continuous support to the faceplates, prevents local plate buckling, and transfers sufficient shear between the faceplates such that their full plastic capacity can be reached in tension, compression, bending, and any combination thereof. The flexural stiffness and strength of the sandwich plate is tailored to meet particular structural requirements by selecting appropriate thicknesses for the sandwich elements. For tank floors, an SPS 6-15-existing (mild steel) design is often proposed; thus the design comprises of a 6 mm top plate, 15 mm core and the existing tank floor plate.

The composite installation process uses the existing corroded or worn plating as one side of a steel composite panel formed by a new top plate and an elastomer core (Figure 1). It is constructed by fitting perimeter bars (steel flat bar sections) to the existing plating, and the new top plate to the perimeter bars to form a shallow watertight cavity into which elastomer is injected to fill the void. The elastomer chemically bonds to the internal steel surfaces to form a fully integrated composite structure.

Performance characteristics

In order to obtain acceptance/approval from regulatory bodies worldwide, the composite has been subjected to extensive testing which is now backed-up by in-service performance experience. The technology has been used for a host of applications including fuel oil storage tanks and cargo tanks of floating production, storage and offloading units (FPSOs) and oil carriers.

Case study: oil storage tank roof repair

The SPS composite was used by Hellenic Petroleum to repair 45 m² of corroded roof on tank 8770-B at the Megara tank farm, which was reinstated whilst the tank remained in service. The repair removed the risk of water ingress, potential fire/fuel ignition and roof sinking, and is approved as an alternative to conventional steel repairs on land-based oil storage tanks, in accordance with the requirements of API 653 and EEMUA 159.

After cleaning and preparing the existing roof plating to the required standard, perimeter bars (steel flat bar sections) were fitted to the existing deck structure using structural adhesive (Figure 2). A new composite steel top plate was then secured to the bars using the same material, thus creating several cavities, as shown in Figure 3, into which the elastomer was subsequently injected to complete the reinstatement. Once the installation was complete, the composite panel created by the bonding of the solid elastomer core to the top and bottom face plates have strength in excess of the original plating. The process was extremely safe, quick and used a fraction of the man hours required for a conventional repair.

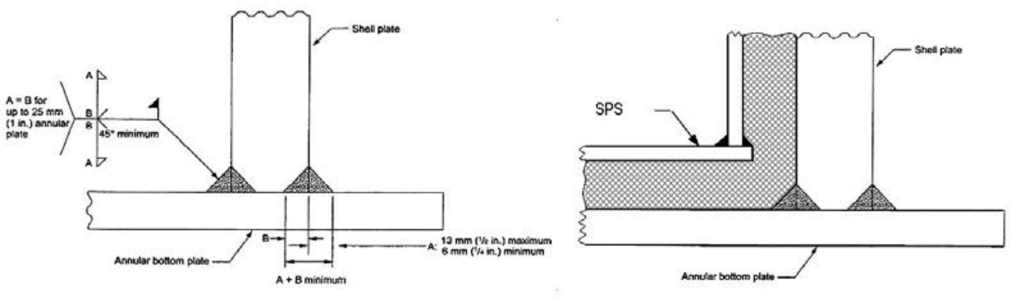

Figure 5. Detail of shell-to-bottom joint (API-650) before and after SPS application.

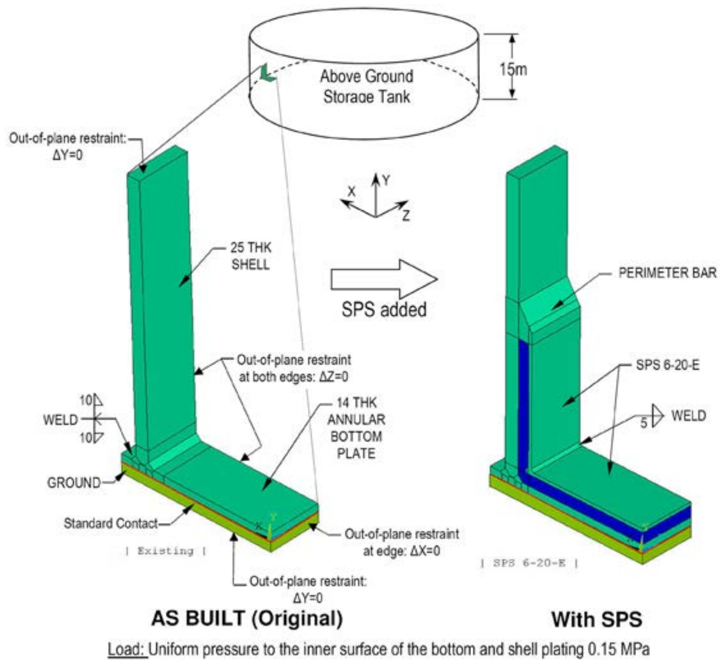

Figure 6. FE models.

Repair of tank shells and bottoms

Repairs, such as the one presented in the case study, can be conducted to extend the life of corroded storage tank shells and bottoms that exhibit signs of pitting corrosion and perforation, which causes small crude oil leaks, contaminating the soil below the tanks. SPS can be used as a permanent repair where the existing steel is used as the bottom faceplate of the composite plate. Since the soil underneath may be contaminated with crude oil, a no hot work solution is required to prevent ignition of the substrate. The perimeter bars can be connected to the existing tank floor using one sided structural fasteners. The top faceplate is then welded on top of the perimeter bars, as the heat from this weld process is insufficient to ignite any flammable soil contaminants. Figure 4 shows typical details for an application on the storage tank shell.

Fatigue characteristics enhancement for the annular ring weld

Aboveground steel storage tanks are subjected to fluctuating pressures from tank filling/emptying operations and thermal expansion. These pressures introduce high stress ranges in the fillet weld between the tank shell and bottom annular ring plating (Figure 5), which often results in low cycle fatigue damage and weld cracking. The composite can be installed on new storage tanks or retrofitted to existing storage tanks as a patch to enhance fatigue performance of critical structural details. The use of the structural composite optimises the through-life performance of the critical shell-to-bottom fillet weld connection detail on storage tanks. In addition to enhancing fatigue characteristics, the composite creates an extra barrier to protect against leaks and spillage.

To demonstrate the improved fatigue performance of the SPS design, a representative analysis has been carried out to compare a typical shell-to-bottom connection detail, both before and after the application (Figure 5).

The performance of the shell-to-bottom fillet weld was calculated using the ANSYS finite element analysis (FEA) package. Two models were created to represent a typical structure without SPS and the typical structure after it had been applied (Figure 6). The static linear elastic analysis was completed and the results compared. A nominal uniform pressure of 0.15 MPa was applied to the inner surface of the shell and bottom plating. Gravity loads were excluded.

The maximum von Mises stress in the as-built tank structure plating adjacent to the weld toe of the shell-to-bottom fillet weld was 148 MPa. This reduced to 18 MPa at the same location once the composite was applied, which corresponds to a stress reduction of 88%. Given that the number of cycles to failure is inversely proportional to the magnitude of a stress range cubed, the fatigue life of this detail is enhanced by more than two orders of magnitude.

Once the composite is fitted, there will be load sharing between the original structure and the installed top plate. The maximum stress at the welded corner of the top plate is 112 MPa. The proposed welded connection detail is a double continuous fillet weld, similar to the shell-to-bottom fillet weld, and more than doubles the fatigue life achieved without SPS. The location of this stress is on the inside weld of the connection between the vertical and horizontal composite top plates. This can be easily inspected during routine tank surveys and repaired if necessary. If a fatigue crack did occur, the elastomer core would protect against leaks and spills of liquids. The stress levels on the opposite side of the vertical top plate are 50% lower and are much less susceptible to fatigue damage. It should be noted that the fatigue performance of this construction detail could be further improved by increasing the core/steel thickness and/or using a radiused corner detail instead of a double continuous fillet weld between top plates.

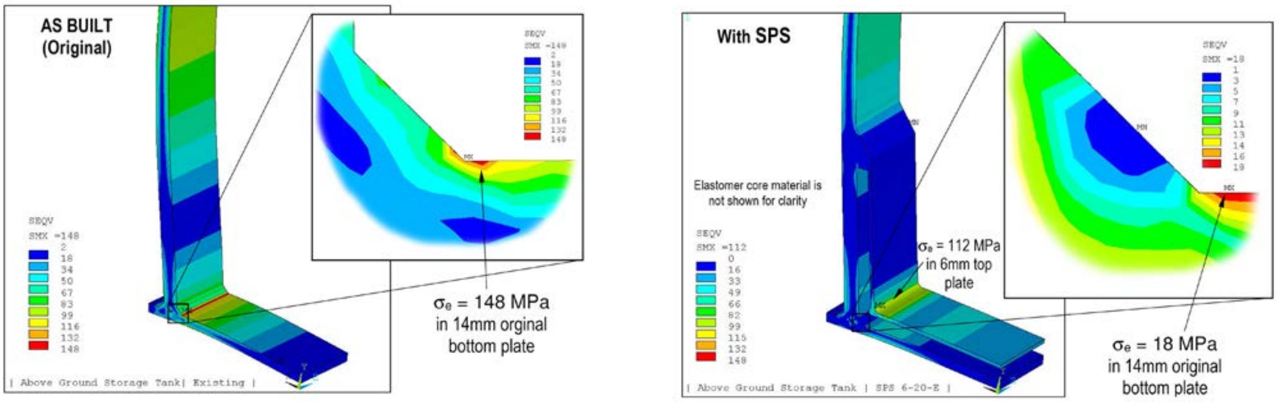

Figure 7. Von Mises stresses in shell-to-bottom joint.

The results of this investigation indicated that the fatigue performance of the shell-to-bottom fillet weld can be significantly enhanced by installing the composite.

Preparing for the next chapter

At the time of writing, the medium to long-term outlook for the oil markets is rife with uncertainty. There is a general sentiment that this is only the 'end of the beginning' of the COVID-19 crisis, with a second wave and corresponding crash in oil demand remaining a genuine possibility. Furthermore, questions remain regarding whether a high level of compliance with the OPEC+ agreement that followed the Saudi-Russian price war will be achieved, with poor compliance levels galvanising the glut of supplies in the market. To remain resilient and profitable in these circumstances, owners of aboveground storage tanks rightly acted early and robustly at the outset of the crisis, protecting their staff and preparing their assets to ensure service continuity. For those operating ageing structures, utilising a composite repair could offer a fast and permanent steel repair with no hot work and, critically, no time out of service – maximising revenue generation opportunities and supporting a strong balance sheet as the oil markets continue to face strong headwinds.

Reference

1. ELLIOTT, R., 'Wanted: Somewhere, Anywhere, to Store Lots of Cheap Oil', *Wall Street Journal*, (11 May 2020).