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futurities

The Simulation Based Engineering & Sciences Magazine

Year 21
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Spring
2024

SPOTLIGHT

A world on water

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Germany

[automotive CAE GRAND CHALLENGE]

// ARTIFICIAL INTELLIGENCE, MACHINE LEARNING, BIG DATA:
HYBRID TWINS BASED ON SIMULATIONS AND COMPONENT TESTS

// OCCUPANT SAFETY: **HUMAN BODY MODELS FOR OCCUPANT SAFETY, ESPECIALLY AUTONOMOUS VEHICLES**

// MATERIAL MODELING - FOCUS CRASH ANALYSIS: **MATERIAL AND FAILURE MODELS FOR CAST METALS, ESPECIALLY GIGA-CASTINGS**

// CAE PROCESS & QUALITY ASSURANCE:
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// DURABILITY / FATIGUE: **DURABILITY AND FATIGUE OF BATTERY PACKS, THEIR HOUSINGS AND SUPPORTING STRUCTURES**

// MULTI SIMULATION: **COUPLED ELECTRO/THERMAL/CHEMICAL/FLUID ANALYSIS OF BATTERIES**

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- Editor's Note

Welcome to the first issue of Futurities for 2024. This issue holds a treat for all of you that work in engineering for offshore structures. Our **Spotlight** this month is turned to the field of offshore engineering – arguably one of the most challenging environments for engineers. The latest study released by Energy Maritime Associates (energymaritimeassociates.com), or EMA, reports projected orders up to $178b for as many as 168 floating production systems, mainly Floating Production Storage and Offloading (FPSO), Floating Liquefied Natural Gas (FLNG) systems, and semi-submersibles for production.

With this massive growth projected, *Futurities* focuses its attention on the specific engineering challenges presented by the offshore environment, whether the structures are intended for extracting minerals and hydrocarbons from the seabed, or for capturing and converting alternative energy sources, such as wind or wave power. The in-depth article written by oil and gas industry engineering veteran, Livio Furlan, delves into all the specific structural and operational challenges presented by the offshore and marine environment and discusses how numerical simulation is used in the design of the structures and in their engineering to prepare them to meet and continue operating over their long service lives. He also discusses how simulation is used to test the structures to ensure they meet regulatory standards and certifications to ensure their robustness and safety, while achieving the most cost-effective solutions for the different scenarios.

The **Spotlight** also contains an article original published in the *Horizon Magazine* with a much more superficial look at how digital twins are being used in offshore engineering to assist with planned maintenance by predicting which parts are most prone to failure. Our third article in the section looks at a new software release from SDC Verifier that simplifies structuring engineering to streamline design, finite element analysis and standards verification. The software can be used both for old and new structures, which is vital considering the long operational life cycle of offshore structures, between 25 and 50 years.

This article in this issue's **Technology Transfer** section looks at Cybernet Systems' Multiscale.Sim, an analysis system designed to help engineers to predict the behaviour and physical properties of viscoelastic materials more accurately and easily, using a new viscoelastic curve-fitting tool, which has several unique features compared to the functionality offered by generic CAE tools. The tool is available as part of the Multiscale.Sim add-on to Ansys Workbench for multiscale analysis.

Our **Know-how** section we have an industrial use case from Carraro that shows the uses of a digital modelling tool for fluid dynamics and thermal analysis for optimizing electrified power transmission systems in off-road vehicles. Identifying and addressing potential issues early in the development phase is crucial to minimize the need for experimental testing, which can cause delays with substantial economic consequences.

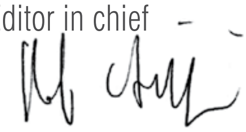
The regular **Research and Innovation** section provides a brief overview of the European research projects in which EnginSoft is already involved across different sectors in 2024, including: BioStruct, a manufacturing process for bio-based fibre-reinforced composite parts for structural applications; ACCURATE which will use manufacturing as a service, digital twins and ecosystems to achieve resilience in manufacturing; ODE4HERA, the Open Digital Environment for Hybrid-Electric Regional Architectures; and YOGA to create miniaturized cartilage tissue-culture wells for point-of-care diagnosis and personalized treatment of osteoarthritis. By 2023, EnginSoft had participated in 100 national and European projects as a partner or coordinator, which has led to significant benefits for the company.

The **Product Peek** in this edition introduces a methodology developed by TSNE for using Ansys EMC Plus, a simulation software to precisely analyse electromagnetic interference, electromagnetic compatibility, and cable crosstalk, to model and analyse twisted shielded pair cables. The software enables Ansys users to simply configure harness cables thanks to the Discovery GUI.

We hope you find the edition as interesting and stimulating to read as we did to produce.

Stefano Odorizzi

Editor in chief



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EnginSoft S.p.A.
24126 BERGAMO c/o Parco Scientifico Tecnologico
Kilometro Rosso - Edificio A1, Via Stezzano 87 • Tel. +39 035 368711
50127 FIRENZE Via Panciatichi, 40 • Tel. +39 055 4376113
35129 PADOVA Via Giambellino, 7 • Tel. +39 049 7705311
72023 MESAGNE (BRINDISI) Via A. Murri, 2 - Z.I. • Tel. +39 0831 730194
38123 TRENTO fraz. Mattarello - Via della Stazione, 27 • Tel. +39 0461 915391
10133 TORINO Corso Marconi, 20 • Tel. +39 011 6525211

www.enginsoft.com
e-mail: info@enginsoft.com

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SPOTLIGHT

Tackling the engineering challenges of offshore oil and gas production

The world's largest oil producer, Saudi Aramco, believes that oil demand will reach a record of 104 million barrels a day in 2024[1] in spite of the global push towards the use of sustainable energy sources and electric vehicles. CEO Amin Nasser states that sustainable energy has not yet proved it can take the place of hydrocarbons for existing requirements, or at the existing price levels.

According to a paper[2] presented at the Offshore Technology Conference in Houston in Texas in the USA in May 2017 by Francois Ars and Renato Rios, there are more than 12,000 offshore installations around the world that have been deployed since 1947. Information available on the UNEP's Global Marine Oil Pollution Information Gateway[3] states that offshore production produces around 30% of global oil and around 50% of the natural gas.

Due to the particular engineering challenges and the associated cost and technical difficulties, oil and gas production is moving towards the use of floating production systems. The latest "Floating Production Outlook Report (2024-2028)" released by the Energy Maritime Associates (EMA)[4] sees demand increasing to $173 billion within the next five years.

In our two-part feature article in this month's **Spotlight**, Livio Furlan explains how numerical simulation is used to design and plan structures that will resist the specific environmental characteristics of marine mineral resource extraction, as well as its role in meeting standards and regulatory certification.

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[1] www.reuters.com/business/energy/ceraweek-big-oil-executives-push-back-against-calls-fast-energy-transition-2024-03-18/

[2] F. Ars and R. Rios, "Decommissioning: A Call for a New Approach," presented at the Offshore Technology Conference in Houston in Texas in the USA, May 2017. doi: https://doi.org/10.4043/27717-MS

[3] oils.gpa.unep.org/facts/extraction.htm

[4] energymaritimeassociates.com/blog/bebuilder-2136/

A world on water | Part 1

by Livio Furlan
EnginSoft

Oceans are the Earth's dominant element, covering more than two-thirds of its surface. They stabilize the planet's temperature so that life as we know it can exist, and they provide the water vapour that falls on the continental "islands" as rain – generally a source of life but sometimes the cause of dramatic flooding, especially now with the increasing effects of climate change (whether it is man-made or not).

Throughout the ages the oceans have been, on the one hand, a natural barrier that has separated, and on the other hand the conduit by which some nations have boldly moved driven by the allure of the unknown – sometimes subduing other nations by force, other times spreading culture, sharing resources and knowledge.

What is certain, however, is that the oceans' extremely inhospitable nature forces humanity to have to depend on "bases" on land for support and sustenance. Over the centuries, sea storms and extreme weather events have destroyed even the largest vessels and ships, just as they now frustrate human attempts to protect coastlines from the onslaught of unsustainable forces of nature.

The Arctic, the ocean at the northernmost tip of the planet, is almost completely covered by perpetual ice, while the Antarctic, the world's southernmost ocean contains huge icebergs that stretch as far as the eye can see.

Opportunity and challenge, security and terror, wealth and destruction: these are the everlasting paradoxes of the planet's oceans and seas.

A bit of history…

Since before recorded history, the seas were sailed in conquests and used for transport, to provide food, and to dispose of waste borne by the rivers along which various civilizations built their villages and cities.

The Phoenicians sailed as far as Norway in the north and Cape Town in the south – perhaps even as far as South America; the Polynesians crossed the Pacific sighting the great wall of the Andes on one side, which they marked as the "end of the world", and Japan and Indonesia on the other; while the Kerala's navigators reached Africa and Indonesia thereby completing primitive man's circumnavigation of the globe. Modern nautical "knowledge" is largely based on the accumulated experience of all these navigators. Nonetheless, it is a

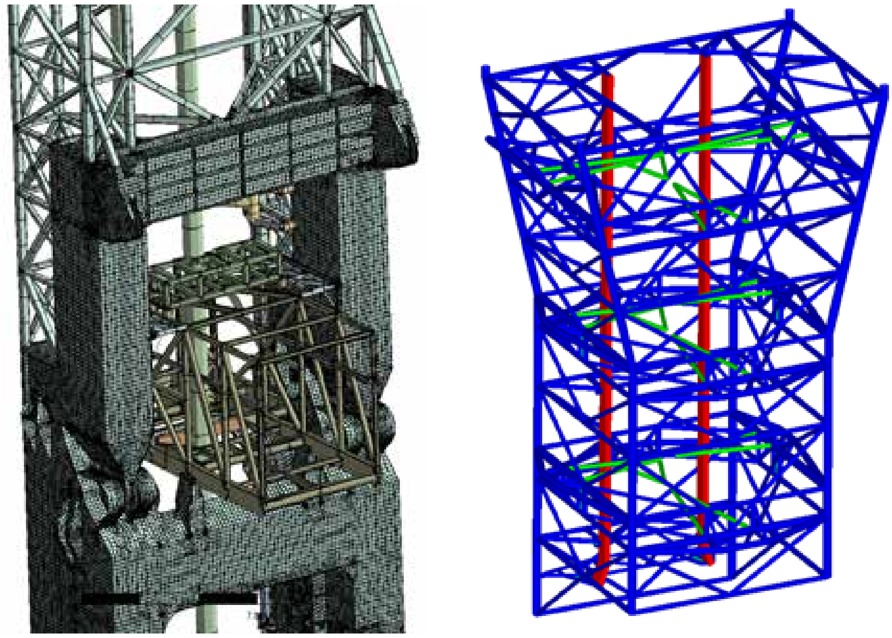


Fig.1. Finite element models of a portion of a J-launch tower (left), and a Bell-Mouth (right)

science that sits at the crossroads between several disciplines, specifically astronomy, geography, and meteorology, as well as the use and application of measuring and observational instruments. Later came the Arab sailors whose maritime empire stretched from West Africa to the Philippines; the Vikings, who sailed as far afield as Canada, Greece and North Africa; and finally, the Western European navigators during the Age of Exploration, who braved the remotest corners of the globe, including both the Arctic and the Antarctic.

In addition to being a vast resource of food, since the second half of the last century oceans have also been definitively recognized as a potential source of thermal energy, although Ocean Thermal Energy Conversion (OTEC) projects while technically feasible are not yet economically viable.

Also since the second half of the 20th century the oceans and their sediments have been fully recognized as a major source of mineral wealth and hydrocarbons to the extent that offshore oil and gas still provide almost one-third of the world's energy needs.

More recently, in addition to the immense publicity given to manganese nodules covering vast areas of the tropical and subtropical seabed, the scientific world was excited by the discovery in the rifts of the seafloor of hot springs, their strange new life forms, and their deposits seemingly rich in polysulphide minerals.

Minerals – salt, trivially – have been extracted from the sea since prehistoric times whereas, in modern times, magnesium and bromine have been extracted from coastal sediments rich in deposits of precious minerals such as gold, tin and, probably, chromium and platinum.

However, most recent maritime construction activity has focused on the installation of structures to meet the needs of the oil industry due to the enormous economic importance of offshore oil and gas and consequently of developing technology for its exploitation.

The contractual aspects and development phases of offshore projects

Many offshore projects therefore concern the extraction of marine resources recognizable as oil and gas. The sovereign nation with jurisdiction grants leases for the exploitation of deposits in specific offshore areas to an oil company, with corresponding provisions for royalties and taxes, and for the development of operations. The concession may involve specific agreements concerning possible alliances with other companies and/or contractors, training and employment of local people during construction, mandated use of local manufacturers and suppliers and the local purchase of materials, and research activities to benefit the grantor nation.

Once it has the lease in hand, the operating oil company conducts extensive geophysical and seismic surveys and it is during this phase that it drills surface cores to obtain bathymetric data and environmental information. Typically, floating vessels, drill ships and/or semi-submersibles are used for exploratory drilling in deep offshore waters, while jack-ups are used in shallower areas.

If the presence of a reservoir is confirmed by these exploratory surveys, the oil company performs delineation drilling to determine the actual characteristics and extent of the reservoir. While gathering more accurate and site-specific geotechnical and environmental data for use in the design and intensifying its planning operations for the offshore development, the oil company simultaneously conducts feasibility and preliminary engineering studies to select a concept for the offshore structure and identify potential contractor tenderers.
The position of operator is highly sought after by oil companies as it confers control of the project, along with substantial fees to cover operating and general costs in most cases. In addition, this role allows the company to develop in-house engineering expertise and advanced management skills.

Once the project is approved, the operator proceeds to finalize contracts for the construction and installation of the offshore platform. In many cases, these contracts cover the following phases:

- substructure design,
- deck design,
- substructure construction,
- purchase of process equipment,
- construction of the deck and its preparation for equipment installation,
- substructure installation,
- deck installation,
- connection offshore,
- production drilling.

Many of these phases are combined into logical groups (Engineering, Procurement, Construction – EPC) before being awarded to a single contractor.

Pipelines are used to transport the crude oil or liquid by-products from extraction/production sites to loading ports, from unloading ports to refineries, and from refineries to shipping ports for the finished products.

The following activities are related to this aspect:

- submarine pipeline design,
- pipeline procurement,
- pipeline lining,
- pipeline installation, possibly involving the digging of trenches to support the pipelines to ensure their stability.

A crucial activity in pipeline installation at sea concerns the design and construction of the laying equipment.

Shallow and/or medium depth waters require an S-launch configuration using Stinger, which is a lattice launching ramp positioned at the stern of the installation vessel (e.g. Saipem's Castoro 6 or CastorONE). The pipeline is progressively built inside this vessel and then runs along these ramps into the sea.

In deep water, a J-launch configuration is used. It consists of actual towers equipped with appropriate equipment to progressively fabricate the pipeline to be laid that are installed on the deck of the launch vessel (e.g. Saipem's SSCV S7000). The J-launch configuration also features a Bell-Mouth lattice structure at the exit point of the pipeline from the launch to prevent its over-bending.

The J-launch tower, Bell-Mouth (or Flute), and Stinger are among the offshore structures that can be classified as fixed (as they are tied to the vessels on which they are installed) and, as such, can be designed/sized (a description of the design phases of a fixed offshore structure is provided in part two of this article).

Obviously, the actions induced by waves and currents (on the Stinger and Bell-Mouth); the forces transmitted by the pipeline during launch; and the inertial forces generated by the surge, sway, heave, roll, pitch and yaw of the vessel during launch must be considered when designing these structures. The surge, sway, heave, roll, pitch, and yaw motions are characterized by the RAOs (Response Amplitude Operators) typical of each vessel.
While on the topic of Flute, in 2014 EnginSoft collaborated intensively with De Pretto Industrie on its engineering development. Built by De Pretto Industrie, the Flute was to be installed beneath the J-launch tower of the S7000, along the launch line of pipelines to be laid on the bed of the Black Sea for the South Stream Project (see the article published in the EnginSoft *Newsletter*, issue 3, 2015).

After installation, drilling begins from the platform. In many cases, production begins after a few wells have been completed while drilling for other wells continues. Once all the wells are operational, periodic workovers are necessary to ensure their continued productivity.

As mentioned previously, most oil and essentially all gas shipments (deliveries) are made via pipelines to a coastal terminal. Some of the gas is, however, retained and used on board the platform to fuel its operation. Oil can also be shipped via tankers. In this case, a subsea pipeline runs from the platform to a loading buoy for direct transfer, via a rotating header, to a tanker moored at the buoy.

This is the case of the Vega field, located approximately 12 miles south of the southern coast of Sicily, off the coast of Pozzallo. In 2012 and 2013 on behalf of Susanna Donà's engineering studio, EnginSoft assessed the extension of the operational life of the Single Point Mooring (SPM) by creating finite element models of the column, the universal joint, the triaxial joint and the hinge joints (see Fig. 2) after which associated numerical analyses were undertaken to determine the stress field distributions in order to calculate the fatigue damage using the deterministic approach.

During a platform's operational life, maintenance, repairs, and modifications (brown field activities) are required. Although these are usually relatively minor operations compared to those in the green field (i.e. during new design, construction, and installation), they are often just as demanding in terms of technical skills and specialized equipment.

Regulations in most countries state that when a reservoir/field has reached the end of its operational/economical life (usually after 20-30 or even 40 years), all structures are to be removed (decommissioned) and the wells are closed and sealed with cement.

The need to transform unprofitable or decommissioned facilities (assets) can be viewed as an opportunity to give them a new lease of life: decommissioning creates employment and the chance to regenerate raw materials and assets that have reached

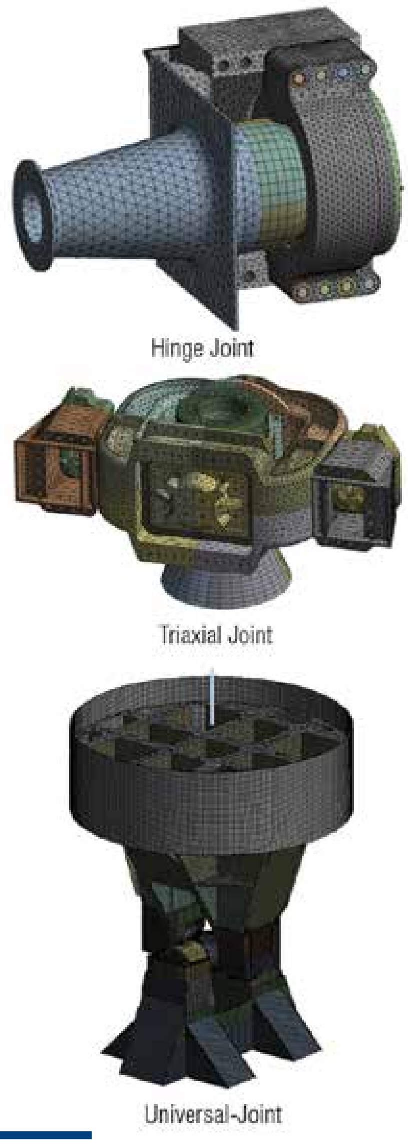


Fig. 2. Finite element models of the parts of a single point mooring (SPM).

the end of their original industrial life cycle but that still have potential for reconversion and reuse in other initiatives. For example, some offshore structures, after reaching the end of their life due to the depletion of deposits, can be redeveloped as facilities to start up offshore marine science parks, or as facilities for environmental monitoring, or for use in renewable energy, or potentially even converted into hotels, sports centres, or diving resorts.

The interaction between design and construction

The installation of an offshore structure requires feasibility studies, planning, preparation and, eventually, execution. Generally grouped under the term" construction", these operations involve many design-related activities, including engineering, all of which must all include an appropriate degree of sophistication/detail. Once completed, the structure is required to function adequately under normal service conditions but it must also safely withstand extreme environmental events and foreseeable accidents. This means that the structure must not suffer progressive collapse as a result of earthquakes, impact from icebergs, extreme storms or even ship collisions. It must also withstand the repeated loads typical of the marine environment, considering that an offshore platform can undergo, for example, up to 200,000,000 or more wave load cycles during its operational life.

Careful consideration of the numerous construction requirements and their interaction with design, regulatory requirements, the environment, logistics, economics, time, risk, and reliability led to the development of the concept of "constructibility", a term to describe an evolving process that lasts for many years. Constructability denotes a continuously progressing framework that has a specific input at each phase of an offshore project, from conception to maintenance, and from repair to eventual life extension and removal.

Thus, it can be said that the demands and challenges of offshore construction, be it for the production of hydrocarbons or green energy, make it one of the most exciting fields of engineering which tests the ability to reach new levels of skill and commitment.

Physical-environmental aspects of maritime and offshore construction

The oceans present a unique set of environmental conditions that determine the methods, equipment, support, and procedures to be employed in offshore construction. This same unique environment, of course, also dominates design.

The following is a brief description of the main environmental factors that act simultaneously and which therefore must be considered in the development of an offshore facility project, whether destined for use for oil and/or gas extraction or dedicated to the production of green energy (wind power).

Depth

The average depth of the oceans is about 4,000m, with the maximum depth being over 10,000m (which is deeper than Everest rises above sea level). Constructions have already been conducted at depths of 1,500m, exploratory oil drilling operations at 6,000m, and offshore mining tests at similar water depths.

Ocean depths, even the "common" levels at which many offshore facilities are located, are inhospitable and mostly dark and therefore require special equipment, tools, and procedures for location, control, and communication. Innovative technologies were developed to meet these needs: specific work submarines, remotely operated vehicles (ROVs), fibre optics, and acoustic imaging.

Depth is associated with hydrostatic pressure and thus it is important to recognize the limits that depth still imposes on phenomena of unstable equilibrium which can induce the instantaneous and unfortunately dramatic collapse of submerged structures.

Hydrostatic pressure is a function of depth according to the well-known linear law:

$$p = \rho g h$$

where:

- p is the pressure (force per unit area)
- ρ is the density of seawater,
- g is the acceleration of gravity
- h is the depth.

The pressure is obviously influenced by wave action: hydrostatic pressure is determined by the elevation of the crest of the wave itself and is greater than the pressure directly below the wave hollow. This effect diminishes with depth: for waves of moderate height the effect becomes negligible after depths of 100m, for storm waves the effect becomes negligible after depths of 200m.

Hydrostatic pressure is related to the concept of buoyancy: a body immersed in a fluid experiences a bottom-up thrust equal in value to the weight of the fluid volume displaced (Archimedes' principle). In the case of a submerged object, its net weight in water can also be thought of as the difference (or closed integral) of the hydrostatic pressures acting on its surfaces.

Currents

Currents, even small ones, have a significant effect on marine operations and offshore construction. They affect the movement of ships and the response of floating structures and moorings, change wave characteristics, exert pressure on structural surfaces and, due to the Bernoulli effect, develop uplift or drag forces on horizontal surfaces (Fig. 3 and Fig. 4). They also create eddies around structures, which can lead to runoff and soil erosion (Fig. 4).

When sea currents run over poles, cables and/or moorings, and pipes (conductors, risers, etc.), a vortex shedding phenomenon may occur, which must be evaluated carefully. In fact, if the frequency of vortex shedding is close to a frequency resonance condition, it produces greater amplitudes of oscillation when the damping and mass of the structure or element are lower.

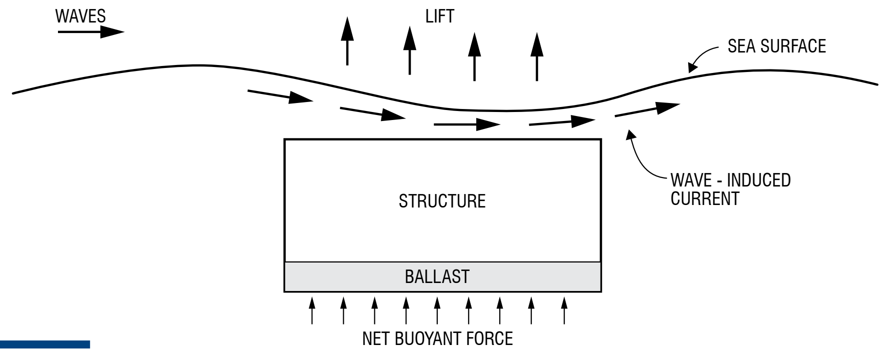


Fig. 3. The "beach effect" - uplift forces on a shallowly immersed structure due to wave-induced current.

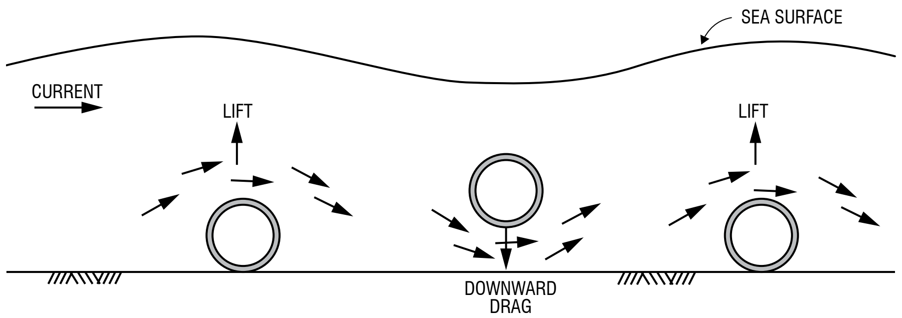


Fig. 4. Oscillating movement of seafloor pipeline due to current.

The vertical profile of currents is conventionally shown as decreasing with depth in a parabolic function. Indeed, recent studies on deep-water projects indicate that in many cases the velocities of stationary currents just above the seabed are almost as high as those closer to the surface.
One important source of currents can be found in tidal changes. The strongest tidal currents usually occur close to the coastline but can extend for a considerable distance offshore where they are channelled by underground reefs or by bathymetry.

Although they generally follow the tidal cycle, tidal currents often lag an hour behind the tide that generated them; thus, a tidal current may continue to flood the surface for a short period after the tide has begun to recede.

Pressure acting on a surface normal to the direction of the current velocity varies with the square of the velocity. Considering that current velocity is superimposed on the orbital velocity of the wave particles, significant drag force effects may occur with pressure resulting in a force proportional to the square of the vector sum of the velocities.

Waves

Waves are the biggest environmental problem for offshore structures and related marine operations. They cause floating structures or ships to respond in the six degrees of freedom (surge, sway, heave, roll, pitch, yaw), thus putting significant strain on all their parts. In marine operations, they can also be the main cause of downtime and reduced operational efficiency. Therefore, for fixed structures, wave forces are generally the dominant design context.

Waves are mainly caused by the action of wind on the water which transfers its energy to the surface layer of the sea through friction. Waves occur when the water is still under the action of the wind. Once these same waves have moved beyond the wind-affected zone as a result of distance or time, they are called swells. Waves and swells can be predicted based on knowledge of the winds. For this purpose, routine forecasts are available for several offshore operational areas. A wave is effectively a travelling disturbance of the sea's surface. The disturbance travels but the water particles within the wave move in an almost closed elliptical orbit with little distinct forward motion. The height of a wave is determined by wind speed, duration, and fetch (the distance travelled by the wind over the open sea).

The total energy of a wave is proportional to the square of its height. While the height of the wave is an important parameter, the period of the wave can be just as important particularly for marine operations. Long-period waves have a great deal of energy, for instance when the length of a moored ship is less than half the length of the wave that sweeps over it, the vessel will experience significant dynamic forces. Waves vary considerably and even simultaneously within a site. Therefore, they are generally characterized by their significant height (Hs) and significant period. The significant height of a wave is the average height of the highest third of waves. If a strong wind lasts less than a minimum duration the wave height will be proportional to the square root of the duration. A sudden gale therefore will not be able to blow up much of the sea.

So-called deep-sea waves tend to travel in groups with a series of higher waves followed by a series of lower waves. The speed of the group of waves is about half the speed of the individual waves.

This means that technicians can wait for of a period of low waves following the higher waves before carrying out some critical, rapid construction operations such as placing a load on a deck or driving a pole.

Average wave height is about 0.63Hs. Only 10% of waves have a height greater than Hs and only one wave in one thousand has a height greater than 1.86Hs; this is often considered the maximum wave height although recent studies show that the value may be closer to 2. Wave height H is the vertical distance between crest and cable and T is the period (i.e. the time elapsed between the passage of one crest and the next over the same point). Wavelength L is the horizontal distance between two crests. Velocity V (often called celerity C) is the speed of propagation of the wave.

Approximate relationships exist between these factors:

$$L=1.56\,T^2$$
$$T=0.8\,\sqrt{L}$$
$$V=L/T$$

Seas are often a combination of local wind waves from one direction and swells from another. Swells from a storm at the site may overlap with swells that are running out ahead of a second storm that is still hundreds of miles away. The result will be confused seas with occasional waves and pyramidal troughs.

Winds

As we have seen, wind is the main cause of wave formation on the sea surface, but as an atmospheric agent it also directly affects the parts of the offshore structure above the water, generating forces on them that are a function of the square of the wind speed as well as the extent of the exposed surfaces. Wind speed increases as one rises above sea level. For example, the wind at a height of 20m may be 10% greater than at a height of 10m (which is the usual reference height for defining the design value of wind speed). Near sea level, wave friction greatly decreases the speed.

Winds are not constant but blow in gusts: a three-second gust, for example, can be one third to one half as fast as the average of the same storm over an hour.

The predominant pattern of oceanic winds is driven by air circulation around the permanent areas of high pressure that cover the ocean, which is clockwise in the northern (boreal) hemisphere and counter clockwise in the southern (austral) hemisphere.

In tropical and subtropical zones, extreme heat and the interplay between the atmosphere and the ocean create deep pressure lows that generate violent storms. These are known as tropical cyclones in the Indian Ocean, the Arabian Sea, and off Australia; hurricanes in the Atlantic and South Pacific; and typhoons in the Western Pacific.

The occurrence of such storms in subtropical and temperate zones is seasonal, from late summer to early autumn, and fortunately still quite rare. In many areas of the world adjacent to dry land, masses of cold high-pressure air can accumulate on land and then suddenly rush out over the sea, generating winds of 100km/h or more (even up to 150–180km/h). Since these winds do not have a long duration, usually lasting only a few hours, the seas are not fully developed and therefore the waves are short and steep.

Tides

Tides are the result of the gravitational attraction of the moon and the sun. Due to their relative mass and distance, the sun exerts only half the influence of the moon on the tides. The highest tidal ranges occur during new and full moons, when the sun, earth and moon are roughly in line; these are called spring tides.

When the positions of the sun and moon form a 90° angle to the earth, i.e. the moon is in the first or third quarter, the tidal ranges are lower; these are called neap tides.

The depth of the sea shown on the charts usually refers to the mean lower low water (MLLW) which is the average low tide height during spring tides. Some authorities use the lower astronomical tide (LAT) as the reference data point.

The tidal excursion in deep seas is relatively low – usually less than 1m – however approaching continental coasts the tidal range can increase dramatically.

As mentioned above, tidal cycles produce currents. High tide has significant flow during the rising tide while ebb is the flow associated with the falling tide. Periods of low or no flow are called stagnant water.

Stagnation times do not coincide exactly with high and low water peaks as water continues to flow for some time after a peak has been reached. Tidal currents are often stratified, with the surface current flowing in a different direction from the current at a certain depth.

For more information:
Livio Furlan - EnginSoft
l.furlan@enginsoft.com

A world on water | Part 2

by Livio Furlan
EnginSoft

As seen in the first part of this article, there is a wide range of offshore and marine structures each of which is suitable for specific situations and, in the case of hydrocarbon reservoir exploitation, this is determined by the extent of the reservoirs themselves, their "productive" capacity, the depth of the seabed, and the weather and environmental conditions.

Fixed structures consist of an underwater part (steel jacket) fixed to the seabed with foundation piles, and an above-water part (deck) housing the drilling and production equipment as well as the modules required to operate the platform.

The jacket is made of steel tubular elements and is the part of the structure most directly affected by the forces of wave action and currents; it is also designed to withstand loads from the deck, as well as the stresses induced by exceptional events such as earthquakes, the impact of supply vessels, and/or icebergs. The deck is the operative area and contains the equipment, apparatus, and modules; it houses both the productive life of the platform and the rest area between shifts. It is important to note that fixed offshore structures are not only used for extracting oil and/or gas deposits. They are also used in the green energy sector (offshore wind farms) to house wind turbines and/or the power plants that transform the energy produced.

In addition to steel lattice jackets, fixed platforms can be constructed of concrete caissons (e.g. the Condeep concept, see Fig. 1), which not only store the product extracted from the field but also provide the hydrostatic buoyancy needed to keep the structure afloat during transport (towing) from the construction dock to the installation site.

Typically, tension rods are made up of several segments. The upper part consists of a cable or rope that acts as a rigid spring in moderate sea conditions. The lower part consists of a heavy chain with clump weights attached to it, which are lifted from the seabed in rough sea conditions, thus activating a "soft" spring-like behaviour that makes the tower more compliant.

Floating, production, storage and offloading (FPSO) solutions are used in fields at great depths, for instance where is both too expensive and difficult to use fixed structures, as well as in marginal fields, i.e. those with limited reserves. Essentially, these are floating units, anchored to the seabed by mooring lines that absorb the weather-induced actions (wave, current, wind). The unit receives fluids (crude oil, water, and a host of other things) through the risers from the wellheads located on the seabed.

The FSRU (Floating Storage and Regasification Unit) is sister to the FPSO solution. A FSRU is a naval unit used as an offshore terminal at which vessels can unload LNG (liquefied natural gas). Once transferred to the FSRU, the liquid product is regasified (hence the generic term regasifier) and fed into the national distribution network.

Another floating moored structure is the tension leg platform (TLP), a vertically moored floating structure typically used for the offshore production of oil or gas but also for green energy (using offshore wind turbines installed on TLPs). This is particularly suitable for waters with depths of between 300 and 1,500 metres. The platform is permanently moored by tethers or tendons grouped in each corner of the structure's hull.

Standards and rules

The design, transport, installation, survey, and maintenance phases of offshore structures are governed by specific rules and/or recommended practices that are laid down by certification bodies and/or internationally recognized associations, including API (American Petroleum Institute), DNV (Det Norske Veritas), ABS (America Bureau of Shipping), and BV (Bureau Veritas). But how is the safety of structures determined?

Calculation and verification approaches – comparison between allowable stresses (ASD) and limit states (ULS)

The first calculation/verification method to be introduced in the standards was Allowable Stress Design (ASD). It is based on purely deterministic criteria, i.e. it assumes that all loads considered cannot exceed their nominal value.

The same assumption also applies to the value of material strengths, which is calculated by dividing the characteristic stress (which can be the yield stress) by an appropriate safety coefficient. The limit state method, also known as Ultimate Limit State (ULS), Accidental Limit State (ALS), and Serviceability Limit State (SLS), was introduced after the ASD method and is semi-probabilistic in nature. The applied actions are considered random and are subject to procedures of combination and factoring with partial coefficients that depend on the probability of occurrence and contemporaneity of the stressing phenomena. These coefficients increase the characteristic (nominal) stresses to obtain the design stresses (F_d).

The characteristic resistances are also treated in random terms, but the coefficients (which are dependent on the importance and reliability assigned to a structural component or welded and/or bolted connection) reduce their values to obtain the design resistances (R_d).

The relationship to be respected therefore becomes:

$$F_d \leq R_d$$

From this standpoint, we could classify the semi-probabilistic method as level I in that it is only compares the scalars (the calculation stress, F_d, and the calculation resistance, R_d), unlike the probabilistic level II and III methods (which actually determine the probability of failure and/or collapse).

Fig. 1. The Condeep platform Troll A. (credit: https://commons.wikimedia.org/wiki/File:Troll_A_Platform.jpg)

Engineering offshore structures

Irrespective of whether they are intended to exploit oil and/or gas fields (even in difficult conditions, e.g. the North Sea) or to produce green energy (offshore wind farms), offshore structures require specific studies and research into design and construction solutions that allow for reliable and safe construction over time.

When applying structural engineering to this sector, engineers must include advanced virtual prototyping, which combines theories and studies on wave motion (and the actions resulting from this) and specialized numerical simulation, which in this sector is highly specific and is therefore generally entrusted to calculation software expressly developed to investigate the behaviour of submerged structures that are subject to hydrodynamic forces when installed.

Sticking to the context of immersed fixed lattice structures (jackets), the wave forces can be calculated by adopting Morison's equation, which sums two force components, i.e. a drag force and an inertia force, as shown below:

$$dF = \frac{1}{2} C_D\, \rho\, D\, U\, |U|\, d_s + C_m\, \rho\, A\, \dot{U}\, d_s$$

$$F = \int_0^{\eta} dF$$

where:

- F is the total force in the direction of the water velocity and acceleration,
- η is the instantaneous water level,
- ρ is the mass density of water,
- U is the instantaneous velocity of the water normal to the axis of the member (component of vector sum of u – horizontal and v – vertical water particle velocity normal to the member) – if a steady current is present, it should be added vectorially to it,
- $\dot{U}$ is the instantaneous acceleration of the water normal to the axis of the member (component of vector sum of $\dot{u}$ – horizontal and $\dot{v}$ – vertical water particle acceleration normal to the member),
- D is the width or the diameter of the section,
- A is the cross-sectional area of the section,
- C_D is the drag coefficient,
- C_m is the inertia or mass coefficient ($C_m = 1 + C_a$ where C_a is the added mass coefficient).

Instantaneous velocities and accelerations (wave kinematics) are calculated on the basis of wave theories such as linear (Airy), Stokes 3rd and 5th order, solitary wave, etc. In addition, Morison's equation applies in cases where the diameter of the membrane struck by the wave is not greater than 0.2 times the length of the wave; otherwise the effects of diffraction and the Froude-Krylov forces must be considered.

The standard form of the Morison equation above assumes that the structure subject to the wave forces is rigid. However, if the structure has its own dynamic response or is part of a floating body, the structure's induced motion may be significant as compared to the wave's orbital velocities and accelerations. In such a case, the "dynamic" form of the equation becomes:

$$dF = \frac{1}{2} C_D\, \rho\, D\, |U - U_b|\, (U - U_b)\, d_s + $$
$$+ C_m\, \rho\, A\, (\dot{U} - \dot{U}_b)\, d_s + (\rho\, A\, d_s - M)\, \dot{U}_b$$

where:

- U_b is the velocity of the incremental section of the structural member,
- $\dot{U}_b$ is the corresponding acceleration of the section,
- M is the mass of the section,
- and the other symbols are defined above.

Morison's equation is applied to each member of the structure to determine the distribution of hydrodynamic forces affecting the structure for each of the monochromatic waves (year wave, 100-year storm wave, etc.) foreseen in the design. The wave profile and its orbital velocities and accelerations vary according to space and time.

It is therefore necessary to identify the maximum position, i.e. the position of the wave in relation to the structure for which the value of the overall hydrodynamic force (base shear load) is highest.

For fixed structures, this is achieved by setting up a "hydrodynamic" numerical model of the structure and passing the wave through it with an adequate number of advancing steps to effectively capture the relative wave-structure position that returns the maximum total shear at the base. The structure's response to the design conditions is determined on the basis of the distribution of hydrodynamic actions associated with the maximum total shear load condition.

To this end a beam-type finite-element model of the jacket structure is developed, complete with foundation piles, and their interaction with the ground simulated by means of p-y and t-z curves, and of the deck structure with the load distribution associated with the equipment, modules, installations, etc. depending on the level of representation required. Detailed finite element modelling studies via shell and solid elements are left for later.

The hydrodynamic forces calculated using the Morison equation for each of the design conditions and for each of the members are added to the finite element model. This results in a virtual "prototype" of the real system that is solved with typical numerical methods of the finite element approach, and which delivers the response of the structure in terms of nodal displacements and stress parameters on the members and foundation piles with sufficient reliability.

Code checks

Regulatory verifications are performed on the identified structural geometries to give the design choices consistency and to locate any weak areas:

- resistance check (also called yield check),
- buckling check,
- combined yield and buckling check,
- hydrostatic collapse check,
- punching shear check (a typical check of tubular knots).

The yield check of a structural element is performed to assess whether the element itself is subject to acceptable stress levels. The check is performed using a yield interaction equation which is defined according to the verification approach adopted: ASD or ULS (see above).

The result generated by verification represents a utilization factor which is the inverse of the safety factor: if the factor is less than 1.0, the member is classified as safe; if the factor is greater than 1.0, the member is classified as unsafe and requires either local or extensive modifications to restore safety.

The yield check is generally performed at both ends and at the midpoint of a member to account for the way the members are subject to stress. However, there may be cases where it is necessary to define additional verification positions along the element to be checked.

The buckling check of a structural element is conducted to assess potential failure through instability in the elastic equilibrium of the element itself when subjected to axial load and bending moments. These are calculated in two orthogonal planes that generally coincide with the brace-chord plane (in-plane-bending) and with the plane orthogonal to it (out-of-plane-bending). The failure check is executed using a stability interaction equation which provides a utilization factor, like the yield check.

Jacket members, which are made of circular tubular profiles, are generally watertight. They may, therefore, experience collapsing phenomena from hydrostatic pressure buckling (hoop stress) particularly at great depths. These effects are combined with the results of the axial and bending stresses along the members. A hydrostatic collapse check is then performed that combines the effect of hydrostatic pressure with the effects of other stresses and includes a check of the elastic instability of the generic member. Here again the verification yields a utilization factor to assess each element's level of safety.

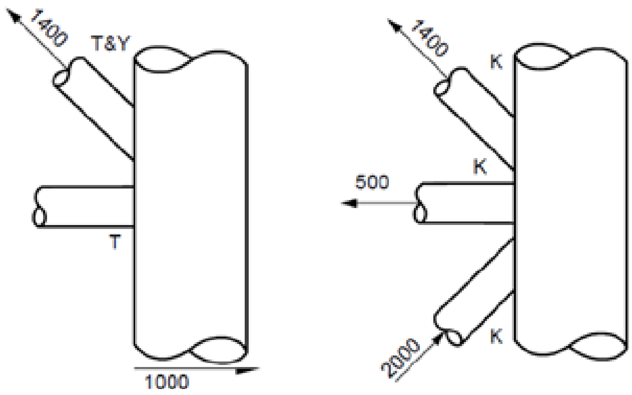


Fig.2 Joint behaviour – Y&T on the left, K on the right (from API RP 2A).

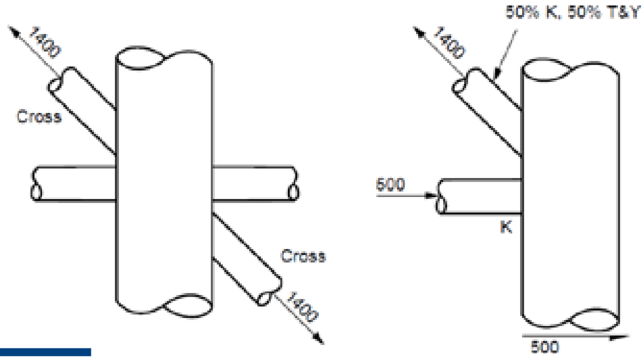


Fig.3. Joint behaviour – X on the left, mixed on the right (from API RP 2A).

The elements of the jacket, whether leg/chord or brace, are made of hollow tubular profiles. A brace is the element that is headed over the through member, which is called a chord (or leg when referring to the jacket legs). A punching shear check of the chords must be conducted at the tubular brace-chord interface/connection.

Tamar jacket on barge H851 with President Hubert on main bridle. (credit: https://commons.wikimedia.org/wiki/File:Tamar_jacket_on_H851.JPG)

Tamar jacket launched from barge H851. (credit: https://commons.wikimedia.org/wiki/File:Tamar_jacket_launch_2.JPG)

This verification assesses the local shear strength of the generic chord subject to the axial load and bending moments that act on the ends of the braces concurring to that chord.

As for the other verifications, this evaluation uses a punching shear interaction equation that yields a utilization factor that is defined by the sum of partial utilization factors, each of which is derived from the ratio between the actions present (axial load, in-plane bending and out-of-plane bending) and the corresponding permissible competence values calculated according to the chord-brace behaviour (Y&T behaviour, K behaviour, X behaviour, mixed behaviour, see Figs. 2 and 3).

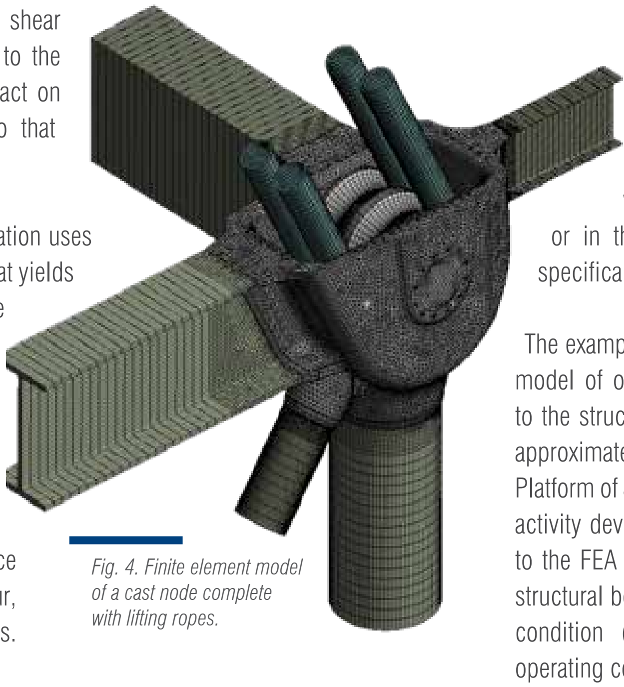


Fig. 4. Finite element model of a cast node complete with lifting ropes.

Finite element model analyses are also used intensively in the design and validation of the geometries of cast nodes for use in congested jacket regions (where the use of welded nodes becomes impossible) or in the case of deck and jackets nodes specifically dedicated to heavy lifting.

The example (Fig. 4) is that of the finite element model of one of the four cast nodes belonging to the structure of the RC002 Module (weighing approximately 95000 kN) installed on the Riser Platform of Johan Sverdrup Field (North Sea). The activity developed by EnginSoft in 2016 referred to the FEA calculation performed to validate the structural behavior of the node both for the lifting condition (heavy lifting) and for subsequent operating conditions.

In addition to the installed conditions (briefly described above) the jacket and deck structures are also affected by other important temporary conditions:

- construction (e.g. roll-ups of the jacket facades/rows that are built in the horizontal plane and then pulled upright to create the structure to be achieved at the end of construction);
- load-out (from construction site dock to transport vessel/barge);
- transport by sea from the construction site to the installation site;
- launching of the jacket at the installation site and subsequent installation (instead of being "launched" into the water from the transport barge, the jacket can be lifted with cranes placed on naval vessels equipped for the purpose - e.g. Saipem's SSCV S7000 or Heerema's SSCV Balder - and placed directly above the wells or placed on the waterline before being definitively installed);
- lifting of the deck (already complete with modules, systems, equipment), again by means of cranes of adequate capacity placed on naval vessels equipped for the purpose, and its positioning on the Jacket which, in the meantime, will have been anchored to the seabed by means of foundation piles.

The structural behaviour of the jacket and deck have to be investigated for each of the temporary phases. This is done using suitable calculation models which consider specific aspects (e.g. for lifting this would include dynamic and skew effects) to determine the stresses for performing the code verifications listed above. Sometimes, in order to assist design and find support from numerical simulation, it may be necessary to develop detailed finite element models e.g. of tubular joints stiffened internally with rings, or of sleeve-leg regions in skirt piles (supported by appropriate portions of the foundation piles connected to the sleeves and, where necessary for the study, simulations of the grout), in addition to overall calculation models.

In this regard it has to be said that, precisely with reference to the assessment of cast nodes strength resistance in heavy lifting condition, EnginSoft has implemented recognized and approved verification criteria based on the categorization of stresses and on the limitation of plastic strains for the regions characterized by (local) structural discontinuities.

An important activity which occurs when the jacket is launched concerns the design of the Auxiliary Buoyancy Tanks (ABT) shown in Fig. 5. These tanks provide the jacket with the necessary buoyancy to remain afloat immediately after launch and define the appropriate trajectory to allow it to self-upend i.e. float in a pseudo-vertical position at the end of the launch operation (see Fig. 6).

For jackets of limited weight and size, these are cylindrical tanks with torispherical or conical heads connected to the main legs of the jacket and subject to external pressure (in order to provide thrust, the tanks

Fig.5. Sabratha jacket's auxiliary buoyancy tanks (ABT). The ABT design was created in 2010.

Fig.6. Sabratha jacket in free floating condition after the launch.

must be watertight and must therefore be verified against the risk of hydrostatic collapse) and the actions that develop during launch.

For larger jackets of correspondingly significant weight, on the other hand, these are "structures" within structures (see Fig. 5) that are still connected to the main legs of the jacket but positioned on the sides of the jacket itself. These are designed with specific methods that consider both the occurrence of external pressure and actions associated with the launch condition and particular geometric configurations, such as the one shown in Fig. 5, which was identified and made feasible by EnginSoft during design activity performed in 2010 for the ABT to be installed on the jacket of the Sabratha Offshore Platform for its launch and self-upending.

The lifting condition of ABTs during their removal is also important, particularly if the tanks are moved filled with water to speed up the operation: water has no weight in water but does have weight as soon as the tanks are lifted out of the water. The design/verification approach followed by EnginSoft for ABTs is the one proposed by "DNV RP C202 – Buckling Strength of Shells", which deals with the topic of stiffened cylinders subjected to external pressure superimposed on axial load, shear loads, bending moments and torque.

Dedicated finite element models with shell elements (see Fig. 7) especially of the "nodes", i.e. the connections between cylindrical tank sections that can have diameters of 5.0–6.0m (see Figs. 8 and 9), enabled the definition of a more reliable, less conservative and lighter design for the ABTs of the Sabratha jacket considering that the key, mandatory engineering objective for these ABTs was not to exceed a ratio of 0.25 of dry weight to thrust (the limit was respected as the ratio reached the value of 0.23).

Fatigue

As previously mentioned, offshore structures, whether fixed or floating and/or moored, experience cyclic stresses induced mainly by wave motion. Therefore, it is essential as early as the design phase to foresee the fatigue response

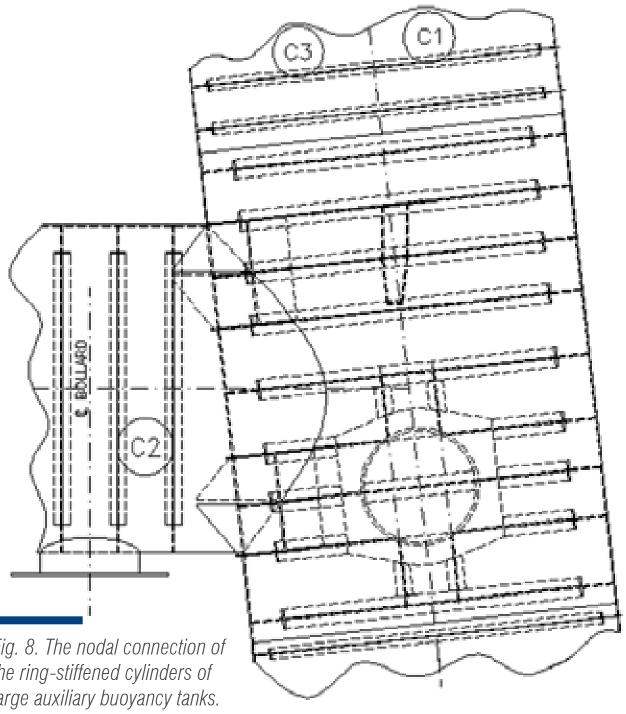


Fig. 8. The nodal connection of the ring-stiffened cylinders of large auxiliary buoyancy tanks.

of submerged structures subject to varying loads, considering that stress concentrations facilitate the development of cracks and hence the achievement of local failure conditions which tends to alter the overall behaviour and can result in a chain of generalized collapse. The overall geometries of the brace-chord welded joints and the detailed geometries of the joint welds thus constitute the factors that influence the fatigue response of fixed latticework structures made up by of hollow circular sections. The overall geometries of the joints are considered by calculating the value of the stress concentration associated with the axial load (SCFa), the in-plane bending (SCFipb), and the out-of-plane bending (SCFopb) given the geometry of the specific joint and its behaviour (YT, K, X). The area involved in this calculation which is the zone that contains the brace-chord intersection curve is called the hot-spot region.

The second factor (weld detail geometry) is accounted for by adopting a specific S/N curve for full penetration welded brace-chord joints.

SCFs can either be calculated on the basis of parametric formulae (Kuang, Wordsworth and Smedley, Efthymiou, Lloyd's Register) or determined by means of finite element models of adequate detail that are validated against parametric formulations on known cases.

By definition, an SCF is the factor by which the nominal stress due to axial force, pure in-plane bending, or pure out-of-plane bending must be multiplied at the stress point in question (located along the brace-chord intersection curve) to obtain the hot-spot stress to be used in the fatigue damage

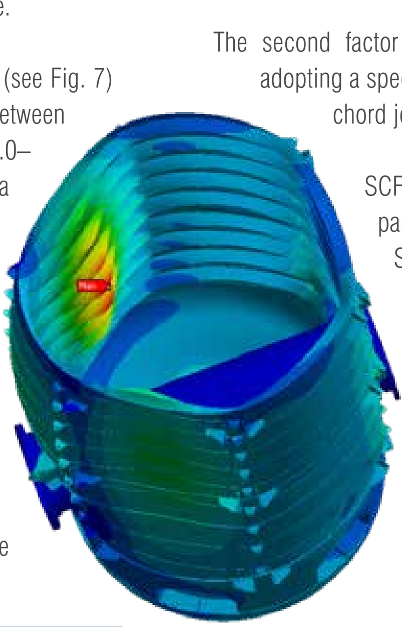


Fig.7. Example of buckling verification of a buoyancy tank.

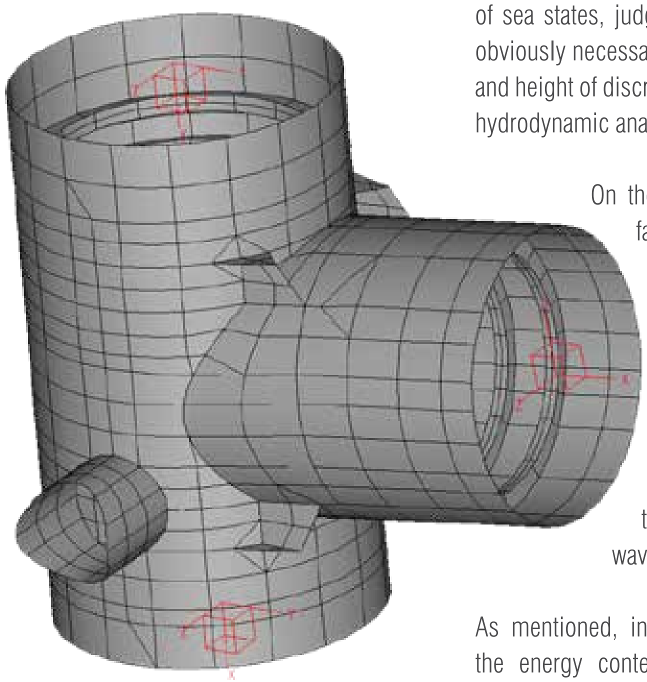


Fig. 9. P-formulation finite element model of the auxiliary buoyancy tanks at the region where the 5.0m diameter ring-stiffened cylinder connects with 5.6m diameter ring-stiffened cylinder.

calculation. It is therefore necessary to first calculate the nominal stresses.

There are two main approaches to determine the accumulated damage in each structural region:

- deterministic fatigue, in which the sea is represented by a series of monochromatic waves of given height and period and the associated number of occurrences for each wave and its incoming direction,
- stochastic fatigue that accurately represents the energy content of the sea states (short-term sea state), each defined by significant height Hs, zero up-crossing period Tz, and probability of occurrence for each incoming direction.

In EnginSoft the deterministic approach to fatigue is applied (and has been applied multiple times) to structures (and components) that are dynamically insensitive or that are located in shallow to medium waters, where both the non-linearity of wave drag forces and the variable submersion of the structure (related only to water depth) are important. Since the method does not directly consider the energy content of sea states, judgment and experience are obviously necessary in selecting the number and height of discrete waves to include in the hydrodynamic analysis.

On the contrary, the stochastic fatigue approach is applied (and has been applied) to dynamically sensitive structures in medium-deep waters, where the non-linearity of the wave drag force is not as important compared to the overall values of the wave forces.

As mentioned, in the stochastic approach the energy content of each sea state is correctly represented, but the fluid-structure interaction must also be adequately considered, since in this approach the structure responds dynamically (albeit in the frequency domain). In fact, situations can occur where the frequencies (fi) of the incident waves are close to the fundamental natural frequencies of the structure, consequently requiring a reliable calculation of the resulting overall force while considering possible wave-cancellations or wave enhancement phenomena.

An example of a specific case of using the stochastic approach for evaluating fatigue damage is the work conducted by EnginSoft in 2019 on the cast components connecting the mooring lines of the Argos FPU (Mad Dog 2 field) to the anchoring suction piles installed in water approximately 1,400m deep.

The distribution of fatigue damage in the cast components welded to the suction piles was calculated by developing a finite element model of the component inserted in the suction pile (modelled in order to define adequate boundary conditions for that component).

Once the standard deviation σ_i of the maximum principal stress at each point of the component mesh for the ith couple of $H_{s,i}$-$T_{z,i}$ inside the Wave Scatter Diagram was calculated, the following equation was used to calculate the damage:

$$D_i = \frac{(p_i T)}{A} f_{oi}\left(2\sqrt{2}|\sigma_i|\right)^m \Gamma\left(\frac{m}{2}+1\right)$$

where:

- D_i is the fatigue damage for the ith sea state Wave Scatter Diagram,
- T is the target fatigue life,
- p_i is the joint probability of Hs,i and Tz,I Wave Scatter Diagram,
- f_{oi} is the zero upcrossing frequency of the stress response,
- A and m are parameters of the different S/N curves considered for the non-welded and welded regions
- Γ is the incomplete gamma function.

The sum of D_i for each sea state i and for each incoming wave direction j provided the total damage D_{tot} at each point of the mooring component's finite element mesh:

$$D_{tot} = \sum_j \sum_i D_i$$

An epoch-making project

As the writer, and writing about offshore issues and structures, it is impossible to overlook an epoch-making project, which was proposed by Italian oil company ENI, and that represents a valid and interesting alternative to the project of the suspended bridge to cross the Strait of Messina between the Italian mainland and the island of Sicily.

The suggested concept consists of three independent tunnels (one for rail traffic, two for road traffic), approximately 6.2km long in water, with an almost elliptical section and of around 6.2km in length. The tunnels would be positioned at approximately 40m below the sea and anchored to the seabed at a maximum depth of 400–450m by means of stays attached to foundation templates fixed to the seabed by piles on one end and to collars installed around the elliptical segments of the tunnels on the other end. These three tunnels would form the three "Archimedes Bridges" (or tunnels in the riverbed) and would exploit Archimedes' principle according to which a body immersed in a fluid receives a bottom-up thrust equal to the weight of the fluid being moved. Since the installation site is characterized by high seismicity, it was imperative to thoroughly examine the structural response of the tunnel-system to seismic events, as well as to tidal currents. It was precisely because of the intensity of the tides that it was decided to move the installation position of the three tunnels with respect to that of the bridge. For this reason, the proposed bridge is approximately 3,600m long, while the tunnels would have been just over 1.7 times the length of the bridge.

EnginSoft's structural-offshore engineering team collaborated intensively with Tecnomare (now EniProgetti) on this specific project and, in particular, on problems of a dynamic/seismic nature. It was the years 1992 and 1993, therefore more than 30 years ago, at the very beginning of the period in which numerical simulation – also thanks to EnginSoft's decisive contribution – began to play a decisive role in the development of complex systems engineering.

The collaboration resulted in the implementation of numerical models to assess the structural behaviour of tunnel-systems subject to hydrodynamic actions and to seismic accelerations. At the time, the latter were derived from the accelerations generated by the El Centro earthquake and were introduced into the models as imposed displacements obtained by double integration of the accelerations. At the same time, again with the aim of studying the seismic response from the geomechanical interaction of the head-tunnel with the ground, localized models were developed of the coastal regions to which the tunnel would be connected by means of large bellows.

After a series of studies, a so-called fan-shaped solution was devised (see Fig. 10), whereby groups of stays would be assembled precisely in a fan-shape. This was done to reduce the number of foundation templates to be installed on the sea floor and, most importantly, to provide the generic tunnel with as constant a vertical rigidity as possible along its axis to minimize the elastic curvature gradients and, therefore, bending gradients/peaks.

Furthermore, compared to the initial configuration characterized by stays placed on vertical planes with respect to the axis of the generic tunnel and frozen in 1987 after a first series of feasibility studies, the fan-shaped solution had lower natural frequencies (than those pertaining to the 1987 solution), meaning mitigation of the seismic response since the fan-shaped structure responded dynamically in areas of the spectrum characterized by lower acceleration values.

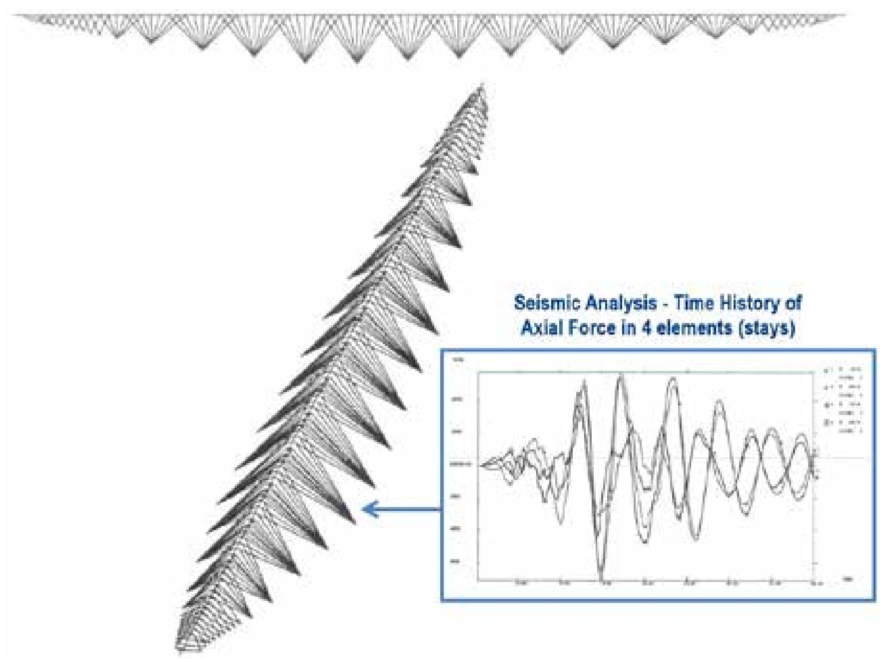


Fig. 10. Messina Strait Crossing – folding-fan solution for the bearing stays of the Archimedes Bridge (project developed throughout 1992 and 1993)

Time-domain analyses developed on one-dimensional finite element models (beams) that had been specifically implemented to accommodate the geometric nonlinearities (large deflections) mainly associated with the behaviour of anchor stays were used to determine the structure's response to both hydrodynamic actions and seismic imposed motion (in term of imposed displacements). These analyses progressively led to the identification and development of the fan-shaped stay configuration.

It should be noted that, at the time, beam models were intensively used to evaluate the seismic response of tunnel systems for two reasons: first, the limitations of computational capabilities required the development and fine-tuning of 'lightweight' models that were functional and compatible with the required representativeness; and second because unidimensional items have provided an adequate level of reliability in studies of overall behavior.

Once post-processed with expertise and wisdom the beam-element models yielded the necessary results. Thereafter the required code verifications of strength and of dynamic stability (particularly for the stays which were

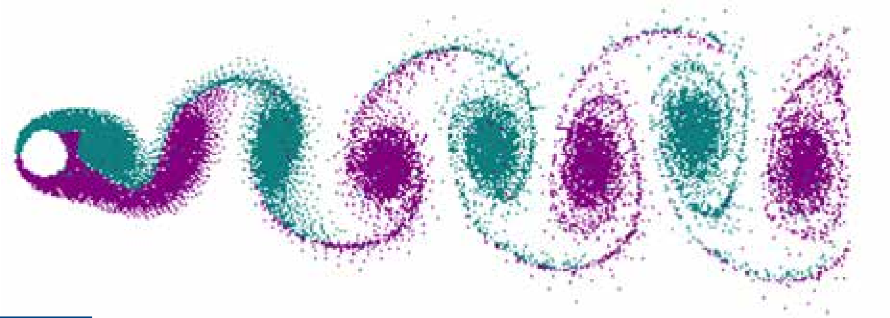


Fig. 11. Phenomenon of alternating vortex shedding. (credit: https://en.wikipedia.org/wiki/Vortex_shedding | Cesareo de La Rosa Siqueira)

actually tubular members) were conducted specifically considering the dynamic nature of seismic actions. To this end, a verification method was developed based on the Russian physicist V. V. Bolotin's treatment of the subject. The issue of vortex shedding on the stays was also addressed since the alternating frequency of vortex shedding in the fluid field can generate resonance phenomena with cross flow (CF) and in-line (IL) vibration – particularly if it is near the eigenfrequency of the cylindrical element, i.e. the stay (see Fig. 11) impacted by the fluid.

Finally, a feasibility study was conducted of the foundation templates and of the connections between the heads of the stays and the templates themselves using detailed finite elements.

Case study: an FPSO mooring system

In offshore oil production involving deepwater fields, for which fixed structure or pipeline installations are technically prohibitive, or in marginal fields whose short operational life makes it economically unprofitable to use these installations, FPSO (floating production storage and offloading) units are used. These floating units are either oil tanker conversions or purpose-built vessels intended for the production, storage, and subsequent distribution of hydrocarbons.

The floating vessel receives hydrocarbons (oil and/or natural gas) from a subsea system of production wells located far from the coast, which is difficult to reach by oil or gas pipelines. As a result, FPSOs are preferred in offshore frontier regions because they are easily installed and do not require special infrastructure or local pipelines to export hydrocarbons. In essence, the FPSO extracts, processes and stores the production of hydrocarbons while waiting for a tanker to load and transfer that production to a port.
An FPSO (also called floating production) contains numerous systems to process and separate different types of hydrocarbons; it also has mooring and dynamic positioning systems able to respond adequately over the course of its operational life to unfavourable but anticipated weather conditions, which must be considered during the design of the unit and its components. As such, an FPSO must operate safely in the face of expected weather and sea conditions.

If these design conditions are exceeded (excessive wave heights due to extreme storm conditions), the unit must be able to "abandon" the site to avoid damage to itself and to the pressure lines that transfer the hydrocarbons from the underwater field to the FPSO. Similarly, when the hydrocarbon production in the field is exhausted, the FPSO must be able to be disconnected and deployed to new fields.

Consequently, FPSOs are equipped with a Disconnectable Transfer System that can be used either on dynamically positioned FPSOs or on FPSOs anchored to the seafloor by mooring lines (catenaries) to keep the unit in the specific production position. In the latter case, in addition to mooring the FPSO, the system ensures the simultaneous transfer, via risers, of hydrocarbons from the undersea wellheads to the unit for subsequent refining, storage, and offloading (transport and distribution).

Among various mechanical and pressure devices, the DTS includes a key component of the multibore type, known as the Quick Connector Disconnector Coupler (QCDC). This connector is the heart of the DTS as it enables instant connection/disconnection of pressurized lines (risers), umbilical lines, and mooring lines. More details on the design and analysis of a multibore connector can be found in the article published in the 02/2013 issue of the EnginSoft *Newsletter*.

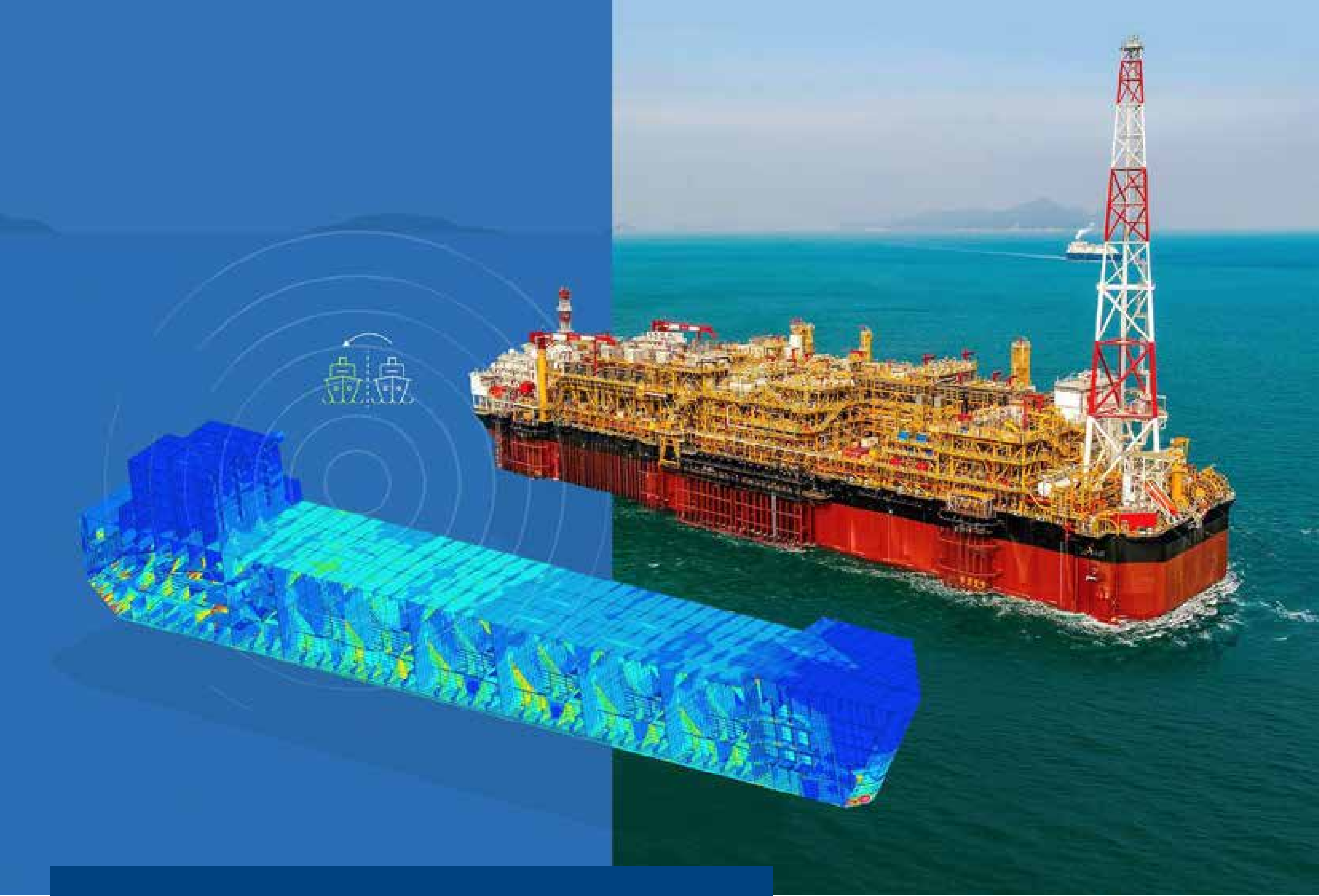
Conclusion

By now it should be evident that the trial-and-error method applicable to industrial production procedures cannot be applied to the unique pieces that populate the critical environment of offshore facilities. Therefore, only a design approach based on virtual prototyping and numerical simulation can analyse and evaluate the different hypothetical scenarios to ensure the required safety and robustness of offshore installations, as well as determine the most cost-effective solution for the different scenarios.

The challenges posed by the marine environment must be met with constant research, application, diligence, humility, enthusiasm, and creativity. The right mixture of these elements allows us to achieve the success here defined as the completion of a project that results in the realization of a structure, since we still need people to generate and develop ideas – even in this age when it appears that artificial intelligence might replace people.

When the right teams are assembled to thoroughly understand the scenarios and environments in which any specific offshore design is planned, there is a high probability of identifying or detecting all the critical conditions and related combinations to be considered in order to overcome the challenges.

For more information:
Livio Furlan - EnginSoft
l.furlan@enginsoft.com



How digital twins are guiding the future of maintenance and manufacturing

Digital replicas of infrastructure such as oil platforms could help prevent accidents by spotting potential ruptures before they happen.

By Tom Cassauwers

As our world becomes more digitalized and connected, we can actually make a virtual copy of it, and such replicas are now being used to improve real world scenarios, from making aircraft production more accurate to preventing oil spills.

A digital twin is a virtual replica of a real-life entity, such as a city or a factory, which often evolves in real-time along with its physical counterpart through data gathered through sensors. It can be used as a testing ground to simulate what happens under certain circumstances or provide alerts of potential problems thanks to predictive algorithms.

A virtual replica of a city might, for example, use all kinds of data sources, from city sensors to meteorological data, to simulate a city's transport system. A simulation could then analyse the effect on air pollution of making a specific zone car-free.

"A digital twin is a concept that describes many things," said Thomas Leurent, CEO and co-founder of Akselos, a Swiss company that builds digital twins for the energy sector. "It can be a 3D image that automatically reflects a physical object (for high-precision manufacturing), but it can also be a model that predicts when maintenance of an oil platform needs to take place."

Using sensors to measure, for example, the strains of structures or wind loads, companies like Akselos make a digital, often real-time, simulation of the physical world. The idea of digital twins, which first emerged in 2002, has its roots in the pairing technology pioneered by NASA who deployed mirrored systems to help rescue Apollo 13. Today, virtual replicas have myriad uses.

Smart city programmes in places such as Portland in the US, for example, use digital twins to model traffic flows; Rotterdam in the

Netherlands is building one of its port to increasingly automate its operations, and attempts have been made to make a virtual copy of the human body for medical purposes.

Wing construction

They are also being used to improve production on the aircraft assembly line. This is the aim of VADIS, a project being carried out by the University of Nottingham and aerospace company Electroimpact, both in the UK.

"We want to improve quality and reduce assembly time for wing construction," said Dr Joseph Griffin, senior aerospace engineer at the University of Nottingham and project manager of VADIS. "We want to measure the holes that need to be drilled in a wing skin, and use those measures to update a digital model. This way we can adjust the construction process to a specific component."

Although many aircraft may look state-of-the-art, some production processes are still old-fashioned and done manually because of lack of digitalization in the industry, which, in turn, can leave room for error. In wing production, for example, holes may not align exactly as they should, which then requires last-minute adjustments on the assembly line, leading to loss of time.

To address this, VADIS is constructing a frame in which the aircraft skins can be scanned by sensors. This will then be used to create a digital model or twin of the wing, with all its surfaces and holes registered in the smallest detail. This model would then be used to build the corresponding parts so that they align seamlessly for that specific wing.

> "We want to improve quality and reduce assembly time for wing construction.
>
> Dr Joseph Griffin,
> University of Nottingham, UK

"Our new system will mean that components can be manufactured very precisely off-site, and the operators only need to worry about assembly," said Dr Griffin. "They don't have to worry about re-drilling and re-working at the last minute." In this way, operators' work becomes a lot easier, he says.

VADIS aims to be able to replicate a digital wing skin of up to 10m long, with an accuracy of 0.06mm, according to Griffin. "[By doing this] we are keeping aircraft production up-to-date and digitalizing it," he said.

Model

Akselos also uses digital twins to improve maintenance of energy infrastructure. The company's technology, commercialized through the Akselos Integra Software, models physics of large-scale energy infrastructure and calibrates the models through all kinds of sensors. "We model everything from the blades of wind turbines to (floating) oil (and gas) platforms that are the size of (several) aircraft carriers," said Leurent.

They might use a robot to inspect the hull of a floating production storage and offloading (FPSO) unit for oil or gas, attach accelerometers to wind turbine blades or measure the height of waves bashing against the metal of an offshore installation using sensors. All of that data then goes into their model, which simulates the physics of the piece of infrastructure and predicts which parts are the most vulnerable and prone to failure. This in turn allows energy companies to send out maintenance crews more effectively.

"The traditional approach is to have scheduled maintenance," said Leurent. "Which yields a huge percentage of what we call false positives. So, a maintenance crew is told to inspect an area, but there is nothing for them to do there. This is hardly efficient, because you misdirect your crews (who in turn lose time), and you might miss problems because you cannot look everywhere."

Of course, you can also statistically predict errors based on previous data. But these models are "very coarse" according to Leurent: they require a lot of data, and still yield high numbers of false positives, particularly for very large objects like FSPOs.

By instead making highly detailed digital replicas, Akselos uses complex models that show companies in real-time where they need to send their maintenance crews.

"This is highly important," said Leurent, "because if you catch a problem early, that's good. But if you're late, you might have a very expensive (repair or) oil spill on your hands."

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projects.research-and-innovation.ec.europa.eu/en/horizon-magazine/how-digital-twins-are-guiding-future-maintenance-and-manufacturing

How SDC Verifier simplifies structural engineering: streamlining design, finite element analysis, and standards verification

by Oleg Ishchuk
SDC Verifier

The cumbersome task of verifying structural design according to numerous standards has always been a challenge. Engineers have found themselves buried under mountains of manuals, struggling with manual calculations, or juggling multiple software programs to model and verify compliance. Recognizing the engineers' pain points, we thoroughly explored the complexities of industry standards and created a solution to simplify the design process. Through tireless dedication and relentless innovation, engineers found that they were able to conduct standards verification directly within Ansys Mechanical, Simcenter 3D, and Femap using SDC Verifier software.

Streamlining structural verification

However, transforming the way engineers approach standards verification has not stopped there. We continue to expand the library of standards, ensuring that our software remains at the forefront of industry advancements.

Each FEA (finite element analysis) model can be automatically verified against numerous prebuilt codes and industry standards such as:

- DIN – Deutsches Institut für Normung or German institute for standardization,
- EN Eurocodes,
- FEM – Federation Europeenne de la Manutention,
- AISC – American Institute of Steel Construction,
- Norsok – standards developed by the Norwegian petroleum industry,
- ISO – International Organization for Standards,
- DNV – Det Norske Veritas certifications for marine insurance,
- ABS – American Bureau of Shipping,
- FKM – Forschungskuratorium Maschinenbau, or mechanical engineering research board, the de facto standard for assessing the strength of metal components in general mechanical engineering,
- DVS – Deutscher Verband für Schweißen und verwandte Verfahren, the German Welding Society, defines quality standards for the joining, cutting, and coating technologies.

Using simulation tools to ensure that the structure meets all requirements for safe operation under all conditions is crucial in many sectors, and the offshore industry is one of those. Due to the extreme environmental factors in which offshore structures operate, they are subject to strict controls throughout their life cycle, from design to decommissioning. SDC Verifier is widely used to troubleshoot and verify projects in the offshore industry, implementing specific standards and regulations such as ABS Plate Buckling (2004 editions), ABS Plate Buckling (2014 editions), API RP 2A-WSD (21st, 2007), API RP 2A-LRFD (1st, 1993), DNV OS-C101-LRFD Weld Strength (2011), DNV OS-C201-WSD Weld Strength (2011), and DNV-RP-C203 Fatigue (2016), and others.

Since 1998, SDC Verifier has been helping industry leaders such as Bluewater, Heerema, Boskalis, TechnipFMC, and SBM Offshore to address the need to check new and old structures, ensuring compliance with the requirements for stability and safe operation in all circumstances and for successful certification.

A paradigm shift in verification

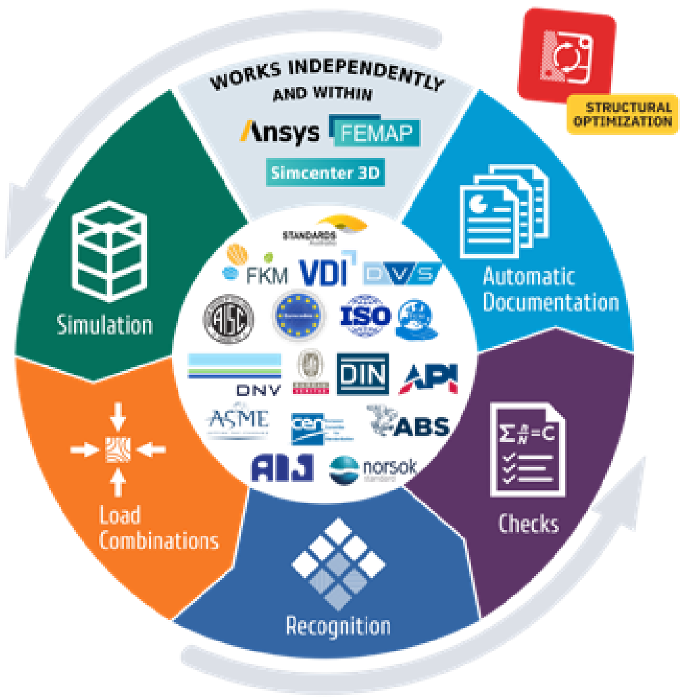
SDC Verifier's journey towards innovation goes beyond simply verifying standards; it's about recognizing and addressing the evolving needs of engineers.

In addition, SDC Verifier has an open API (application programming interface) and a formula editor so that engineers can see all the steps involved in calculating the relevant standard, edit ready-made standards in national annexes, or create a control according to their own rules.

Moreover, there are separate apps for dedicated checks: Beam Member Check App, Beam Member and Joint Checks App, Plate and Stiffener Buckling App, Fatigue App, and code-specific checks such as Eurocode 3, AISC, and FKM. Our software incorporates unique tools that have evolved by analysing common workflow requirements. These tools include recognition tools for detecting beams, plates, welds, stiffeners, and connectors because accurate verification must be based on the structural elements, not the mesh.

The recognition tools allow any structure made of 1D, 2D or 3D elements to be checked, simplifying the engineers' work. Engineers often have to modify the project to define the best possible design, reduce the amount of material, prevent stress concentrations, remove bottlenecks, and ensure that the structure passes all verification and certification stages smoothly. For this purpose, SDC Verifier's Optimization tool helps prepare a range of possible sizes, shapes, thicknesses, or element classifications for each part of the model, striking a balance between design requirements, compliance with industry standards, and the costs of the structure.
Creating calculation reports is a requirement for certification, but it is usually a time-consuming manual task that engineers would like to automate. SDC Verifier has a special tool — Report Designer — which enables the automatic creation of template-based reports and includes all necessary calculation results. Reports can be exported to PDF or Microsoft Word for further editing.

To ensure that our software is accessible to freelance engineers and large companies, we have launched a flexible licensing policy, offering three levels of functionality (for Beams, Beams and Plates, and Full).



As we delved deeper into the industry, we noticed that engineers in specific sectors, such as civil engineering, often require standards verification without requiring full-fledged FEA simulations. To bridge this gap we introduced the standalone program SDC Verifier, an evolution in our software lineup.

This version is specifically designed to meet the needs of engineers who prioritize standards verification over complex simulations. In SDC Verifier, engineers can easily create designs from scratch, as well as integrate existing drawings, 3D files, or finite element models from any software, through a contemporary, user-friendly graphical interface that simplifies the process.

Our parametric modelling functionality simplifies the model creation process, saving time and effort and allowing us to modify only the essential input parameters to create models.

With this innovation, SDC Verifier aims to become the FEA simulation program of choice for thousands of engineers, revolutionizing the way standards are verified in the industry.

Our software allows engineers to innovate with confidence, knowing that their designs meet the highest standards of excellence.

Engineering expertise driving innovation

When we say that SDC Verifier software is created by engineers for engineers, it is not just a buzzword. Our engineering consulting department has not only used SDC Verifier in over 400 projects for almost 100 valued customers but is also actively involved in developing new standards and improvements to the program itself. By exploring our customers' success stories, you can see how SDC Verifier has made a difference in real projects globally.

We also offer structural calculations, digital twin development, and cloud-based engineering solutions to provide engineers with cutting-edge technologies and innovative approaches. In addition, our services include measurements and inspections, standard checks, and personalized support to meet the unique requirements of the engineering project.

Partnering for success

At SDC Verifier, we are committed to providing excellence in software solutions and engineering consulting services, promoting innovation, and exceeding customer expectations at every step. We are more than just a software provider — we are a trusted partner in structural design excellence.

Our mission is simple: to provide engineers and designers with the tools they need to bring their visions to life. We believe that every project deserves the utmost precision and reliability, so we are dedicated to providing industry-leading software solutions that push the boundaries.

For more information:
Alessio Trevisan - EnginSoft
a.trevisan@enginsoft.com

About SDC Verifier

SDC Verifier is a mechanical and structural design engineering company providing all-in-one design and code checking software and engineering consultancy services. Since 1998 we have won the trust of leading global companies in the Offshore and Maritime, Heavy Lifting, Oil and Gas, Defence, and other industries. The SDC Verifier software is a powerful design and standard inspection tool that works independently and within several FEA solutions such as Ansys, Femap, and Simcenter 3D. It helps to automatically verify FEA results against numerous industry standards such as DIN, EN, Eurocode, FEM, AISC, Norsok, ISO, DNV, ABS, FKM Fatigue, and DVS code for weld checks. SDC Verifier's functionality is proven to increase the productivity of engineering teams and take them to a new level of comfort. Contact SDC Verifier when in need of consultancy on FEA, modelling, design review according to standards, or for your other specialized software needs related to FEA or to industry standards.
Visit sdcverifier.com or email info@sdcverifier.com

World leading training in Engineering Simulation and technology available from EnginSoft

Alongside its engineering services, EnginSoft offers a wide range of specialized simulation training courses to help its customers increase their competitiveness and productivity.

The offer covers numerous fields of simulation, from mechanics, fluid dynamics, electronics, and electromagnetism. to multidisciplinary optimisation, digital manufacturing, structural engineering, multibody, foundry and dimensional and tolerance analysis.

Training by EnginSoft incorporates the transfer of knowledge consolidated over 40 years of experience and 4,000 successfully completed projects with our customers in every field of engineering. The resulting offer places the discipline of simulation-based engineering at the heart of our training courses while maintaining the focus on the best technologies that the simulation market provides.

Our authentic learning courses are therefore designed for mutual growth and to address the increasingly difficult challenges posed by the technology market today and in future. Having also participated in over 100 research projects to date, we are also well positioned to offer training on currently trending, forward-focused topics such as digital manufacturing, data mining, digital twin implementation and deployment, and Industry 4.0.

Our content-rich training arms our participants and instructors to take on new challenges together and also features the versatility and professionalism which have always distinguished EnginSoft and our work ethic.

We offer remote and in-person courses either at your premises or ours, with the constant presence of qualified instructors who accompany participants from the very beginning when the training programme is defined. We strongly believe in the importance of interaction and exchange between people and always support our high-level training with continuous and direct contact.

EnginSoft is also able to design and provide comprehensive learning pathways for companies wanting to develop their employees by cultivating their technical-scientific awareness of simulation with an eye to the future of engineering.

Learning pathway design, course implementation, and course delivery are fully managed by a UNI EN ISO:9001 2015 certified quality system. Following the successful extension to the EA37 training sector, all EnginSoft courses are now also eligible for training subsidies and funding.

For any information about our programmes, or to explore how we can collaborate to grow together, please contact the training secretariat: corsi@enginsoft.it or visit enginsoft.com/training

Multiscale.Sim

Innovative curve-fitting tool for viscoelastic materials introduced: Contributes to sustainability from a materials perspective

by Koji Yamamoto
CYBERNET SYSTEMS CO. LTD.

Have you ever grappled with the non-linearity of materials? CYBERNET Multiscale.Sim is an analysis system that easily predicts the behaviour and physical properties of materials without needing to rely on actual tests. In past issues of Futurities, we introduced its ability to predict material behaviour using virtual material testing; this article introduces Multiscale.Sim's curve-fitting feature for predicting material constants for viscoelastic problems.

Introduction

Materials with a low environmental impact are increasingly being used. While there are clearly significant benefits in terms of sustainability, changing materials and maintaining product reliability is never easy. To make matters worse, these new materials are often highly non-linear and therefore difficult to manage in analysis. For example the thermosetting resins used traditionally generate microplastics that cause water pollution, so now reusable thermoplastics are favoured. However, their low melting temperature compared to other structural materials makes it impossible to design with them without considering the material's viscous behaviour.

In many generic CAE tools, a material's viscoelastic behaviour is represented by a material model that combines the generalized Maxwell model with a shift function, as shown in Fig. 1.

Since there are so many material constants, it is impractical to manually fit the material test data onto the material model. This article describes CYBERNET's new viscoelastic curve-fitting tool, that has recently been released as a feature of Multiscale.Sim, an Ansys Workbench add-on for multiscale analysis (see Fig. 2).

What is a curve fitting tool and why use one?

To account for non-linear material behaviour in an analysis, a material model is needed to represent the material behaviour. Material models in structural problems mainly express the relationship between stress and

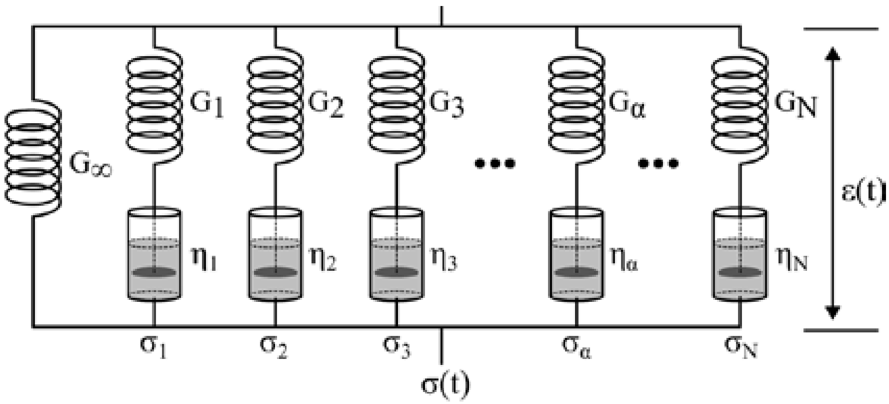


Fig. 1. Generalized Maxwell model to express viscoelastic material behaviour.

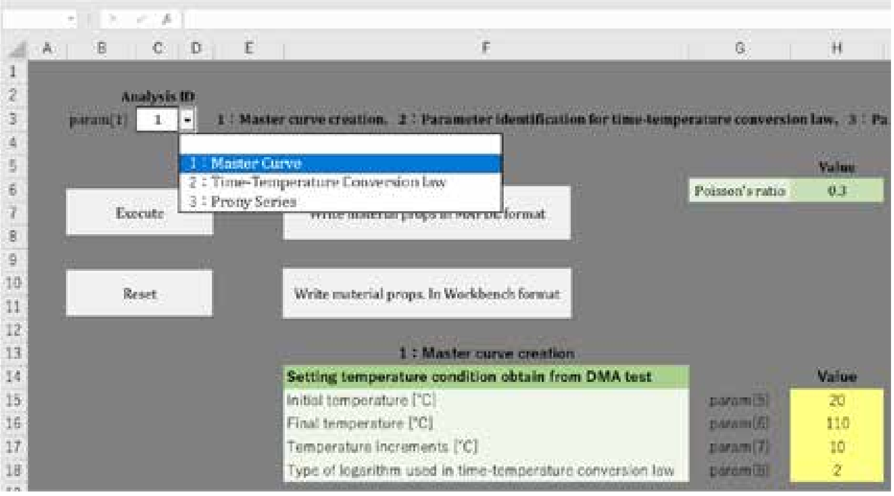


Fig. 2. Overview of curve-fitting tool for viscoelasticity, provided as an option in Multiscale.Sim.

strain in the form of a function with different coefficients (called material constants). These constants express the actual material-dependent behaviour.

In other words, to reflect the material behaviour in the analysis, it is necessary to observe the actual non-linear behaviour experimentally and then adjust the material constants to better fit the data. The curve fitting operation refers to the adjustment of this material constant.

CYBERNET developed the curve-fitting tool because many generic CAE tools do not have sufficient fitting capabilities for viscoelastic material models. The following three issues, specifically, affect both for accuracy and ease of use:

a. Raw data from the dynamic material analysis (DMA) study cannot be used

Existing viscoelastic curve-fitting functionalities, for instance in Ansys software, require experimental data on stress relaxation properties. This may seem natural since viscoelastic material models are formulated as a function of time. However, it is unrealistic to directly determine long-term stress relaxation behaviour through actual experiments because it requires accelerated testing at varying temperatures. Furthermore, frequency rather than time should be used as the arbitrability condition for quasi-static observations of a particular strain rate state. Tests conducted under these conditions are called dynamic mechanical analysis (DMA) tests. It should be possible to perform viscoelastic curve fitting based on raw DMA test data (details below).

b. Shift functions to express temperature dependence are not supported

The temperature dependence of viscoelastic material behaviour is represented by a shift function. Many tools do not provide a curve-fitting function to identify the constants that constitute this function. As a result, users have to deal with this manually or develop their own programs.

c. There is an upper limit on the number of Maxwell elements

Although stress relaxation properties can be obtained with some effort, the number of Maxwell elements can be limited when fitting properties to a curve. This can significantly reduce the expressive power of the material model.

The overall fitting process consists of three steps, as shown in Fig. 3. The next section introduces the functionality of the curve-fitting tool we developed to resolve these problems.

Step 1: Master curve creation

As previously mentioned, it is difficult to directly measure the long-term relaxation behaviour of viscoelastic materials, so their behaviour is typically measured with DMA tests that periodically vary the loads. Images of this test are shown in Fig. 4.

For materials with viscous behaviour, the phase difference between stress and strain is expressed by decomposing the stress into in-phase and out-of-phase components. These are called storage modulus E' and loss modulus E", respectively, and are defined as follows:

$$E' = \frac{|\sigma|}{|\varepsilon|}\cos\theta, \qquad E'' = \frac{|\sigma|}{|\varepsilon|}\sin\theta$$

The applicable frequency bands for DMA tests are also limited. Accelerated tests at varying temperatures are necessary to obtain characteristics over a wide frequency range. For thermorheologically simple

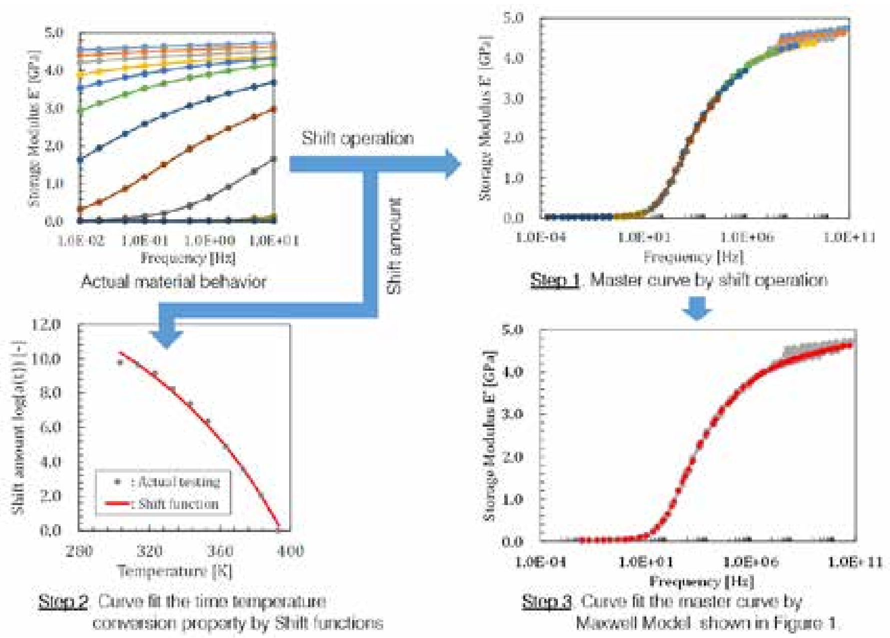


Fig. 3. Operational flow of the curve-fitting analysis to identify material constants.

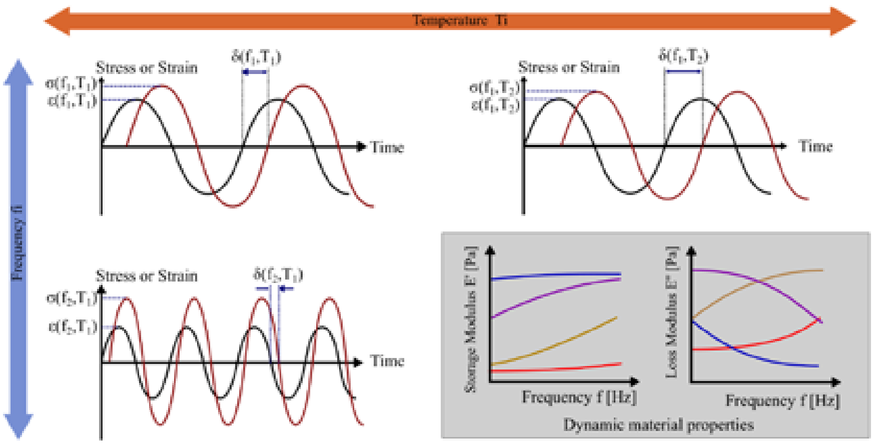


Fig. 4. Images of material testing by Dynamic Mechanical Analysis (DMA).

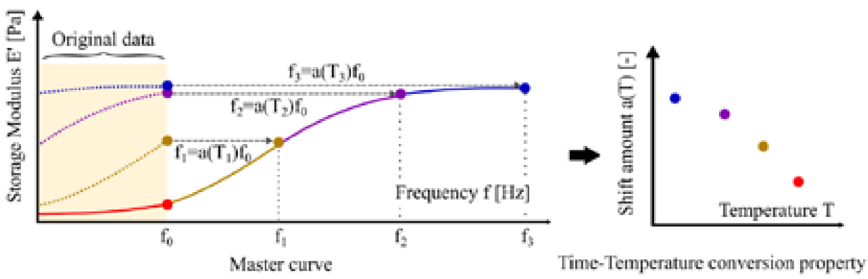


Fig. 5. Creating the master curve by performing a horizontal shift operation.

viscoelastic materials, temperature changes can be matched to changes in frequency (or time). This characteristic relates to the time-temperature conversion law and allows users to virtually obtain the behaviour of a material over a wide frequency range at a specific temperature by taking multiple temperature levels, even for limited frequency range tests. In Step 1 we obtain this characteristic.

The task of converting temperature to frequency corresponds to the operation of converting the frequency-dependent elasticity modulus along the horizontal axis, as shown in Fig. 5. This operation is performed for each temperature to generate a single connected, or master, curve (see Fig. 5). The curve-fitting tool automatically adjusts the amount of shift for each thermal elastic modulus to minimize deviation from the master curve.

Step 2: Master curve creation

The shift amount obtained in Step 1 must also be expressed as some kind of material model. This is called the shift function.

Ansys offers the Tool-Narayanaswamy and Williams-Landel-Ferry (WLF) equations. The former can only be used for analysis in the temperature range below or above the glass transition temperature (hereafter abbreviated as Tg). While WLF can represent the shift behaviour over a wide temperature range across Tg, it is a simple functional form and does not necessarily provide a good curve fit.

CYBERNET has developed Arrhenius- and polynomial-type shift functions in which the shift behaviour changes discontinuously after Tg. Fig. 6 shows examples of time-temperature conversion characteristics for epoxy and PMMA (polymethyl methacrylate) resins using three shift functions for curve fitting.

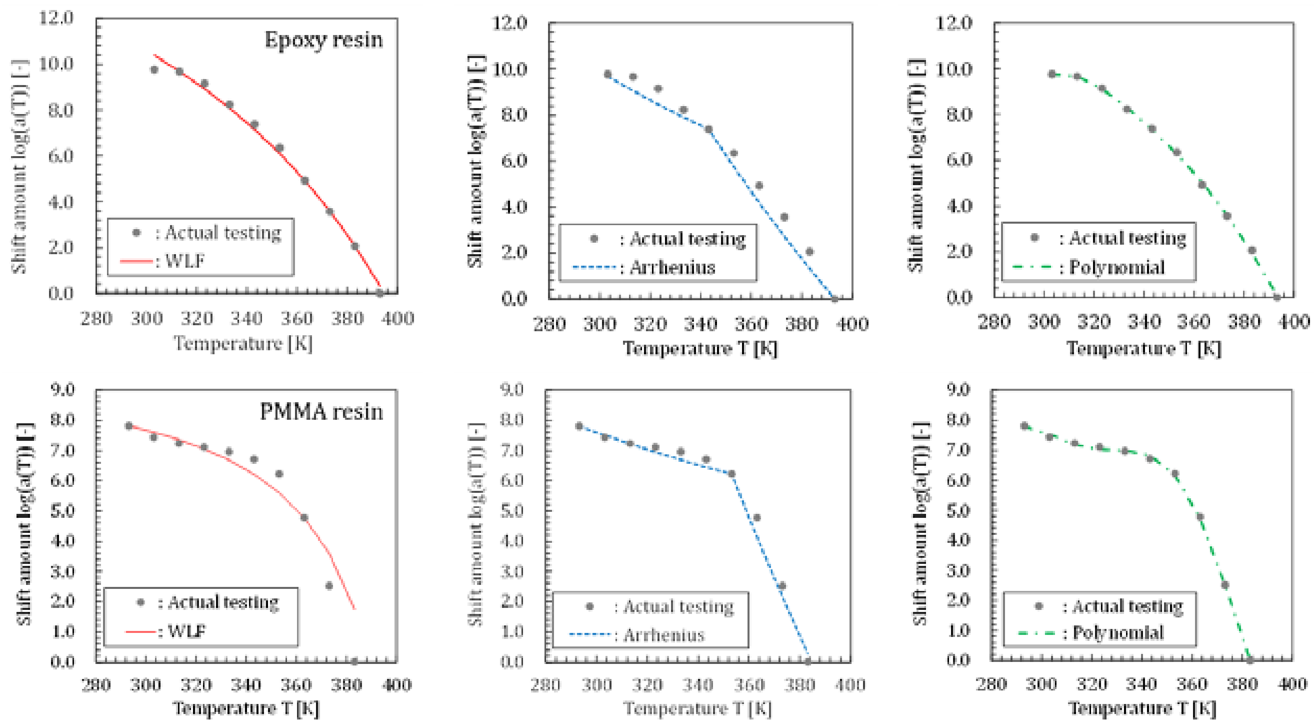


Fig. 6. Time-temperature conversion characteristics of epoxy and PMMA resins fitted using three different shift functions. Of these, Ansys only provides the WLF shift function.

If the properties change discontinuously after Tg, as with PMMA, reproducibility by WLF becomes poor especially near Tg. The polynomial form provides the most rigorous fitting of experimental data, but also allows overfitting for small experimental errors. The optimal shift function to use therefore depends on the type of resin.

Multiscale.Sim provides a rich set of shift functions and robust curve-fitting capabilities, allowing users to account for the temperature-dependent behaviour of different resins in their analyses in a simple and versatile way.

Step 3: Prony series identification

Finally, the master curve obtained by the shift function of the time-temperature conversion law is fitted according to a material model called the Prony series.

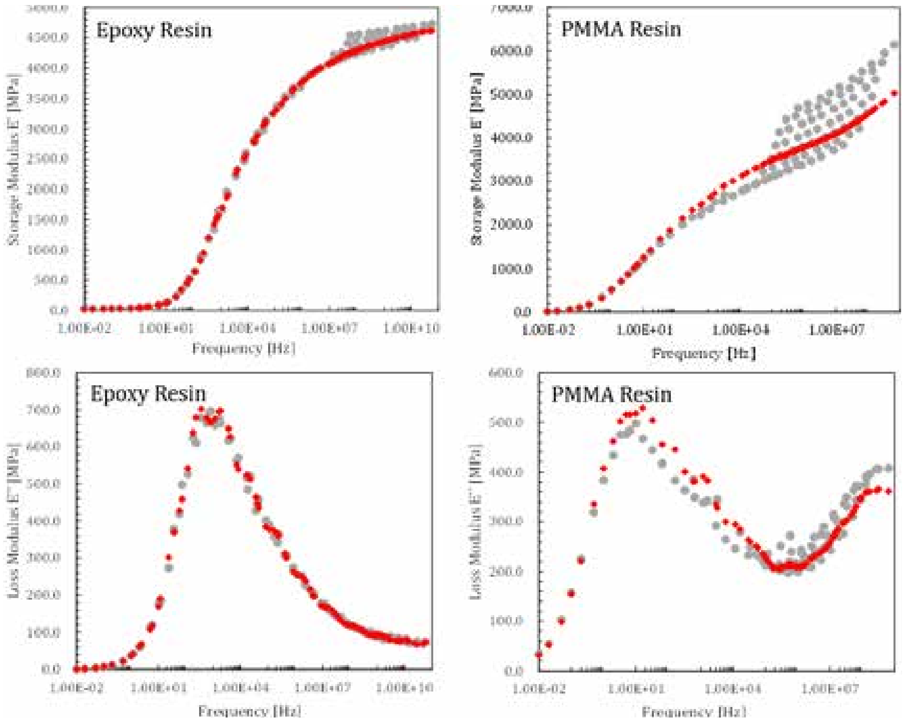


Fig. 7. Master curve-fitting results of the dynamic viscoelastic properties of epoxy and PMMA resins using the Prony series. Maxwell elements were set to 22.

Multiscale.Sim's tool allows the storage and loss modules obtained from DMA tests to be directly fitted rather than using the relaxation modules, with no limit on the number of Maxwell elements. This feature is very important because generic CAE tools incorporate errors associated with the conversion of dynamic viscoelastic properties into relaxation coefficients, and their limited number of Maxwell elements result in poor fitting capabilities.

Fig. 7 shows the master curve-fitting results for the epoxy and PMMA resins mentioned in the previous section. The PMMA resin is on the low temperature (high frequency) side; the test data for each temperature is not listed on the master curve.

This is because PMMA resin has a strong temperature dependency not only in viscous terms of the material properties, but also in elastic terms that shift toward the elastic modulus axis.

To accurately describe this phenomenon, we think it is necessary to introduce a new time-temperature conversion law. We have already built a material model for this purpose and plan to release it in a future version.

Conclusion

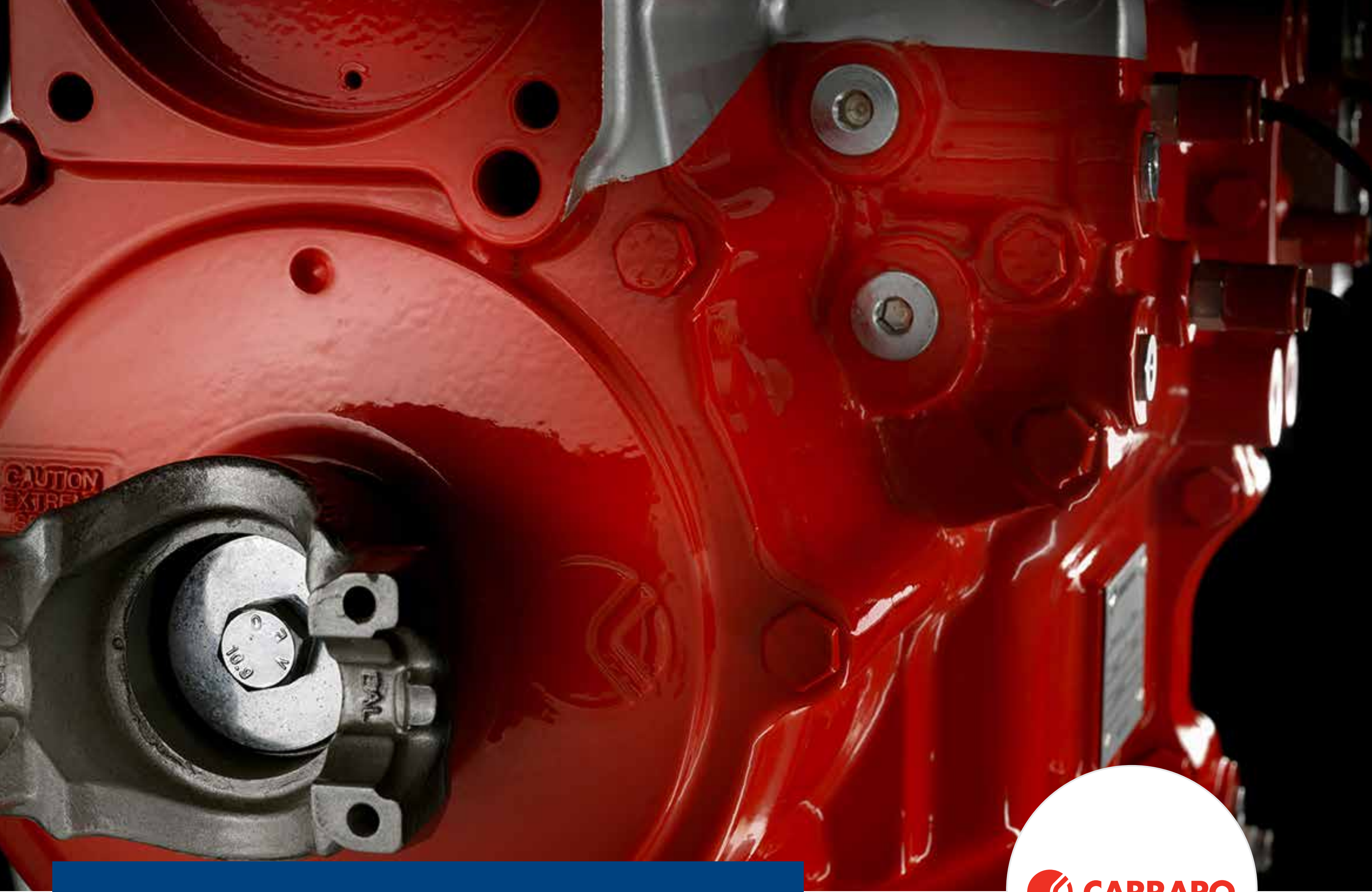
This article presented the curve-fitting tool for viscoelastic properties created by CYBERNET for its Multiscale.Sim tool. Compared to the same functionality offered by generic CAE tools such as Ansys, it has the following unique features:

- The master curve of temperature-dependent viscoelastic properties can be obtained automatically by applying the time-temperature conversion law.
- Three types of shift functions are provided to represent time-temperature conversion characteristics, allowing for a general adaptation of different shift behaviours for different materials.
- Fitting with the Prony series can be performed directly using the dynamic viscoelastic properties instead of the relaxation modulus. In this case, there is no upper limit to the number of Maxwell elements, so good fitting results can be obtained universally for resins with various characteristics.

About CYBERNET

CYBERNET SYSTEMS CO. LTD. is a leading CAE company established in 1985, headquartered in Tokyo, Japan. Its corporate vision is "Creating a sustainable society and inspiring the world through technology and ideas". The company's goal is to solve the problems of its customers, who face increasingly diverse and complex technological issues every day, with technology and ideas that exceed their expectations, and to lead them to the next level of innovation.
CYBERNET is an Apex Channel Partner and a Technology Partner (Software) of Ansys. The company has been developing Multiscale.Sim since 2007 and it is being used by many customers in Japan and in other countries.
For more information, visit: www.cybernet.co.jp/ansys/product/lineup/multiscale/en/
or email: cmas@cybernet.co.jp

For more information:
Francesco Lori – EnginSoft
f.lori@enginsoft.com



The importance of numerical simulation in optimizing electrified power transmission systems

by Massimo Bettio[1] and Michele Merelli[2]
1. Carraro Group - 2. Particleworks Europe, EnginSoft

Off-road vehicles are evolving towards full sustainability, driving the need for solutions that maximize fuel efficiency while reducing atmospheric emissions. To meet the growing interest in electrification, the significant challenge of power loss management in electric engines must be addressed.

Power losses affect drivetrain components, specifically from friction between gears, shafts, and seals, as well as gear churning and bearing losses due to the oil in the transmission. These factors, which are directly related to operating speeds, can cause the internal components and the oil to overheat.

To minimize power loss and maximize transmission system efficiency while ensuring proper lubrication and heat dissipation, oil flows within the transmission and their interactions with dissipation sources must be verified. This verification usually takes place during bench tests using physical prototypes with specific openings to check oil flow, pump suction zones, and proper gear and bearing lubrication. Simultaneously, temperatures and power losses are checked under all operating conditions, including critical ones.

The rise of simulation-aided engineering

Identifying and addressing potential issues early in the development phase is crucial to minimize the need for experimental testing, which can cause delays with substantial economic consequences.

Detailed digital prototypes that use mesh-free CFD modelling, like Particleworks, support engineering R&D for the lubrication and cooling of critical components like gears, transmissions, bearings, and electric engines, in various industries including automotive.

Carraro, a leading manufacturer of transmission systems for off-road vehicles, uses such software and analysis to optimize product development, reduce the risk of reworking prototypes and improve the efficiency of transmissions for electrical applications.

eCarraro – Carraro's integrated proposal

In response to increasingly strict emission regulations and efficiency concerns, Carraro has developed transmissions that integrate electric engines. These transmissions meet the regulatory constraints while reducing emissions and maintaining current levels of performance and productivity.

eTB220C transmission

Developed for all-electric applications, this drivetrain minimizes power loss even at high speeds and ensures flexibility by integrating compact electric engines for multi-stage solutions. This family of scalable electric motors offers low- and high-voltage power sizes and functions.

THE solution: plug-and-play hydrostatic and electric solution

Designed for a wide range of light construction machinery, "THE solution" allows vehicles to switch between hydrostatic and electric applications without altering the chassis or transmission layout. It is suitable for telescopic handlers, backhoe loaders, skid steer loaders, and wheeled excavators.

Hardware and software

In this era of digital transformation, Carraro also offers innovative solutions for the electronic control of transmission systems and vehicles catering to e-mobility. Customized software development supported by Carraro hardware platforms ensures vehicle functions from user interfaces to traction management and the entire electrified powertrain.

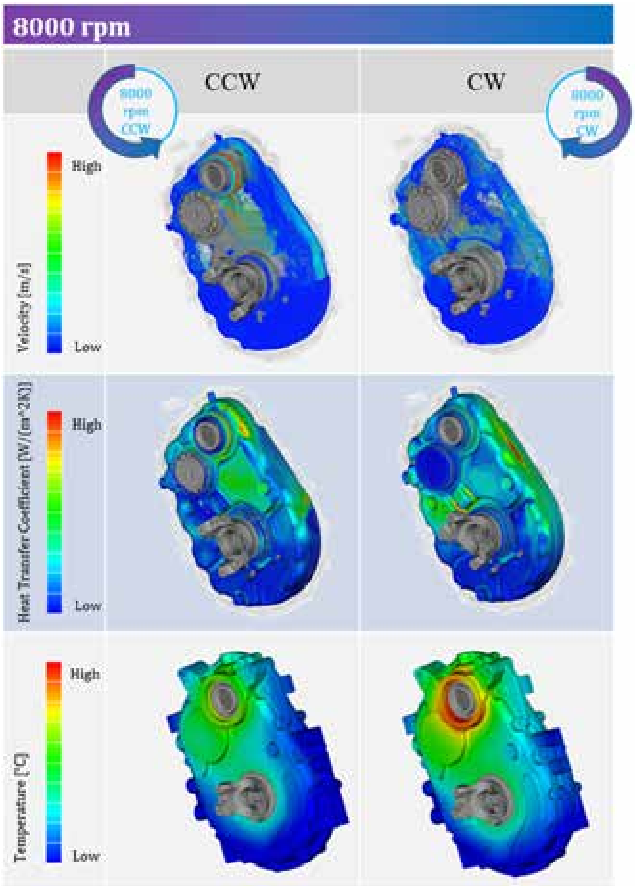


Fig. 1. Comparison of oil distribution, heat transfer coefficient, and temperature maps between two opposite directions of rotation with the same speed at transfer box inlet.

Expanding lubrication analysis and churning loss estimations to temperature estimates

An in-depth analysis of power loss and operating temperatures in electric applications was performed using the specific case study of a compact wheel loader's transfer box, consisting of three shafts and two total gear pairs, for a total input-output ratio of 4,861.

The study aimed to extend the company's simulation workflow by incorporating temperature evaluations at critical points of the transmission and considering heat exchanges and the estimated power losses due to regulations.

Particleworks was used for the fluid dynamic simulations and subsequent conjugate heat transfer (CHT) thermal analyses, which were compared with Ansys Mechanical thermal solvers in a first simulation. The Particleworks simulations were performed on a workstation equipped with an RTX A5000 GPU.

Particleworks thermal model and comparison with Ansys Mechanical

The initial fluid-dynamic simulations assessed the correct lubrication of the bearings and gears and obtained the heat transfer coefficient (HTC) map dependent on the specific oil flow rate of each case study while also extracting the estimated losses due to the interaction of the gears with the oil - part of the total power losses of the system.

The various contributions to the dissipated power were then analysed theoretically with reference to the ISO-TR 14179/2 standard, and compared to the software's estimates and the experimentally measured losses.

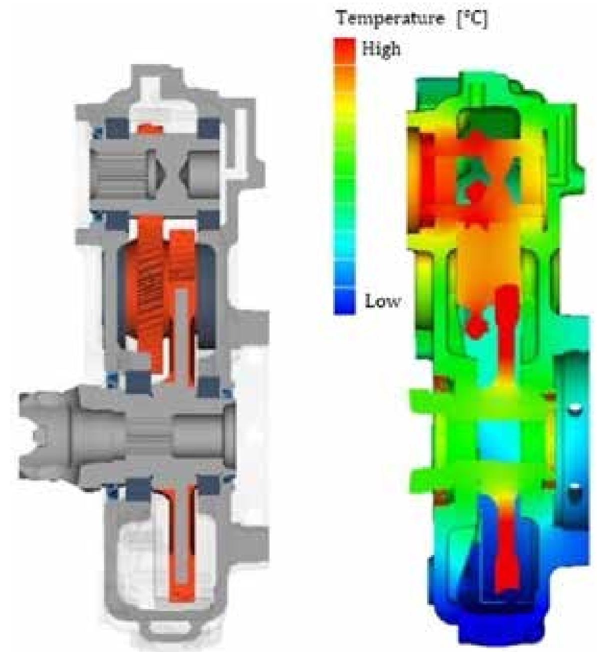


Fig. 2. From the temperature map section of the transfer box, you can see the contribution of each power source: seals, bearings and outer portions of the gears.

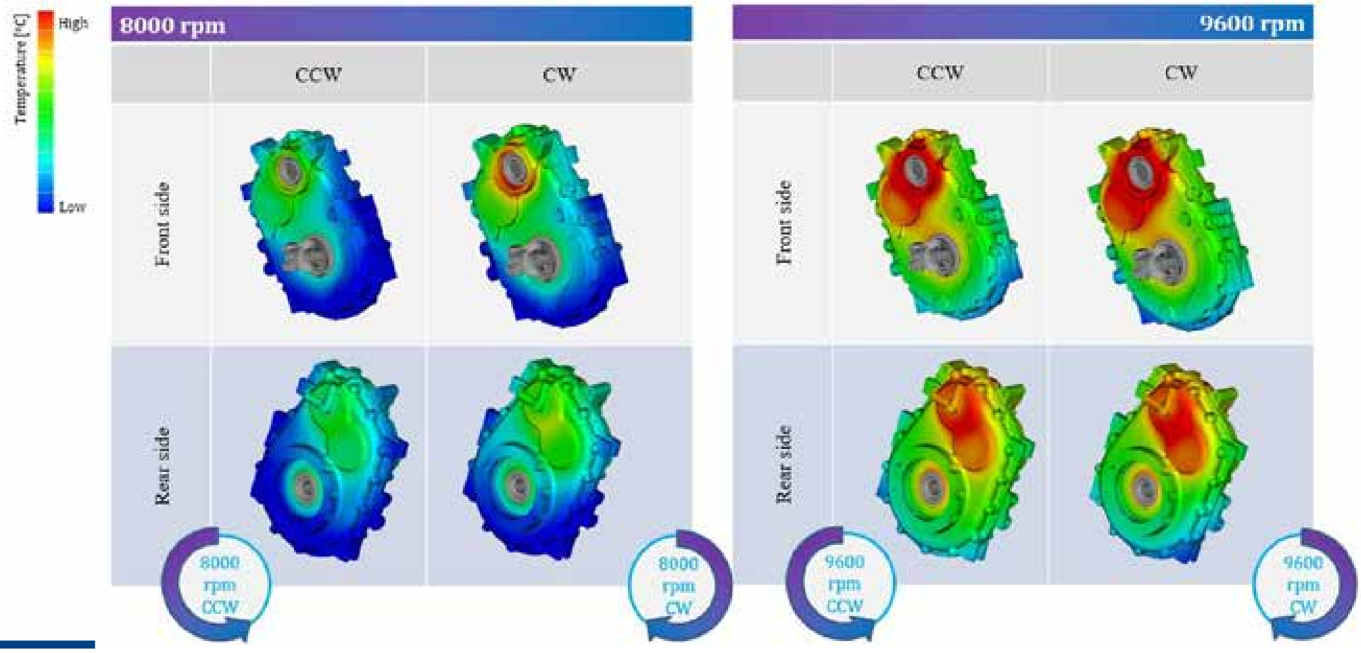


Fig. 4. At higher input speeds transfer box temperatures are superior to the ones at lower input speeds, due to the higher power losses, especially near bearings and seals.

Thereafter they were used as input as heat sources to the subsequent steady-state thermal simulations. In other words, the sealing losses, the bearing churning losses, and gear churning losses were applied to the respective thermal energy source according to the calculations for each single contribution. Only the outer portion of the gears was considered as a power source, since this is the part which has most contact with the oil thereby generating the churning losses.

Firstly, in an analysis undertaken in collaboration with the University of Padua's Department of Mechanical Engineering, two thermal simulations were conducted using the same input data and including the thermal conduction coefficient between the components and the natural convective heat transfer coefficient (HTC) for the external surfaces. The only difference between the two simulations was the inclusion/exclusion of the convective HTC map on the internal surface of the gear box derived from the internal oil flow.

Validation of Particleworks' thermal solver with experimental thermocouples

The results show that the HTC map was a non-negligible variable in this type of thermal analysis since the temperature errors in the simulation without the HTC

Fig. 3. Experimental setup of the transfer box.

Thermal gaps [°C] with experimental measurements - Process 2							
Input speed [rpm]	Input sense of rotation	T_1 [°C]	T_2 [°C]	T_3 [°C]	T_4 [°C]	T_5 [°C]	T_5 [°C]
8000	CCW	-4,6	6,4	9,7	-5,4	1,6	3,6
8000	CW	-2,0	9,6	7,3	-2,1	4,5	5,5
9600	CCW	-7,8	1,8	4,5	-8,7	-5,2	-3,4
9600	CW	-8,6	9,1	7,8	-4,4	3,2	3,6
$T_i = T_{sim\_i} - T_{exp\_i}$							gap < 5°C; 5°C < gap < 10°C; gap > 10°C

Fig. 5. Differences between temperatures estimated by Particleworks simulation and the experimental values at the 6 thermocouples of the transfer box bearings under analysis: the maximum temperature gap was 10°C.

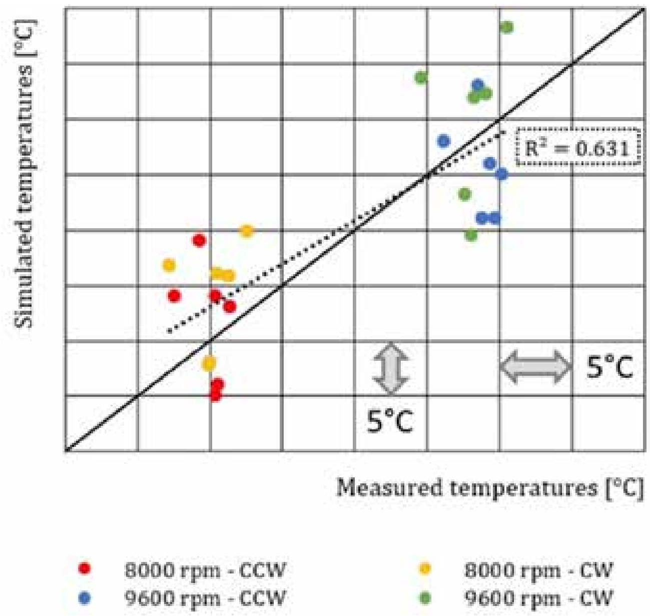


Fig. 6. The values of the second CHT Particleworks iteration were plotted in a graph showing the correlation between the measured and simulated temperatures. The solid line represents the ideal correlation while the dotted line links the trend of all points for which the R2 values were calculated.

map reached 35% when using the experimental measurements as a baseline. In any case these values are in line with the experimental expectations because the exclusion of the HTC map on the internal surfaces of the transfer box causes higher temperatures due to the lack of contribution to the heat exchange and the dissipation of power loss.

Thereafter we compared the results from two thermal analyses with the same input data performed in Particleworks and Ansys Mechanical and, considering the temperature values of the bearings, a maximum difference of less than 10°C was found between the two simulations.

We then compared experimental bearing temperatures to Particleworks' thermal CHT simulations for four operating conditions, considering two different speeds (8,000 and 9,600rpm) with two input rotation directions (clockwise and anticlockwise).

Conclusions

In conclusion, this validated study shows the uses of a digital modelling tool for fluid dynamics and thermal analysis. The easily implemented workflow was used to analyse Carraro off-road transmissions, providing the engineering team with detailed information on temperatures and power loss in the early product development stage.

By using the Particleworks thermal solver to compare four different case studies, we verified that the different speeds of the gears and the different oil distribution within the transmission as a result of the different rotation directions creates a different interaction with the heat sources. Quantitatively, using an HTC map that included the inner surfaces of the gearbox, the seals, and the bearing raceways, the temperature values obtained from the CHT simulations showed a maximum deviation of 9°C compared to the experimental data detected with the thermocouples.

For more information:

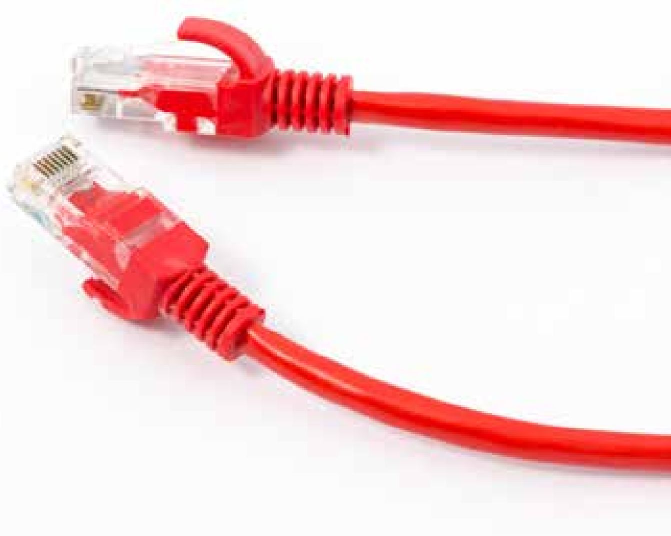
Michele Merelli - EnginSoft
m.merelli@enginsoft.com

About Carraro Group

Carraro (carraro.com) is an international leader in transmission systems for off-road vehicles and specialized tractors. The group has two business areas:

- Transmission systems (axles and transmissions) and components mainly for agricultural and construction equipment; and gears for diverse sectors, from the automotive industry to material handling, agricultural applications, and construction equipment.
- Specialized tractors (for vineyards and orchards, between 60 and 100 horsepower) for third-party brands; and engineering services for the design of innovative tractor ranges.

The group's headquarters is in Campodarsego in Padua in Italy. At the end of 2023, Carraro had 3,859 employees, 1,800 of which were based in Italy, and four manufacturing facilities in Italy, with others in India, China and Argentina.



Cable crosstalk analysis using Ansys EMC Plus

by Dae Hyun Kim
Tae Sung S&E

Ansys EMC Plus is a simulation software that precisely analyses electromagnetic interference (EMI), electromagnetic compatibility (EMC), and cables. This paper introduces a methodology for modelling and analysing twisted shielded pair (TSP) cables using Ansys EMC Plus.

Harness cable

A harness cable combines together several cables used for power supply and signal communication with connectors. Used in vehicles, aircraft, ships, and electronic devices, harness cables are crucial for transmitting stable signals to components designed for specific purposes.

Pre-assembled cables are easy to install, maintain, and manage, ensuring electrical safety and enhancing system reliability. More recently in the automotive sector, the shift from internal combustion engines to electric vehicles has led to a gradual increase in the use of harness cables and wiring in general. Fig. 1 shows a harness cable installed in a vehicle.

Ansys EMC Plus (legacy EMA3D cable)

Ansys EMC Plus is a simulation software that utilizes the finite difference time domain (FDTD) numerical analysis technique to interpret electromagnetic fields. The time domain solver allows you to analyse large and complex structures quickly and accurately. Fig. 2 illustrates the graphical user interface (GUI) of Ansys EMC Plus. Ansys Discovery Modeler gives existing users access to its advantages quickly and easily. The user-friendly interface facilitates efficient interpretation of electromagnetic phenomena.

Analysis of TSP (twisted shielded pair)

1) Creating the harness cable

The process of modelling and creating harness cables in Ansys EMC Plus is very

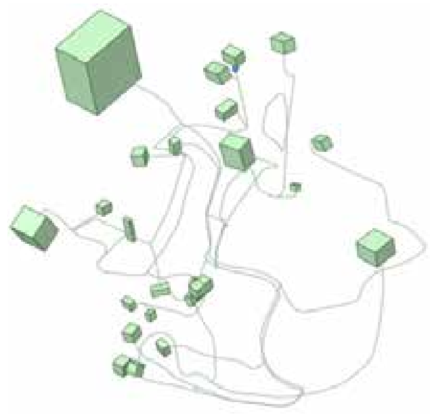


Fig. 1. Harness cable installed in a vehicle.

Fig. 3. Cable type.

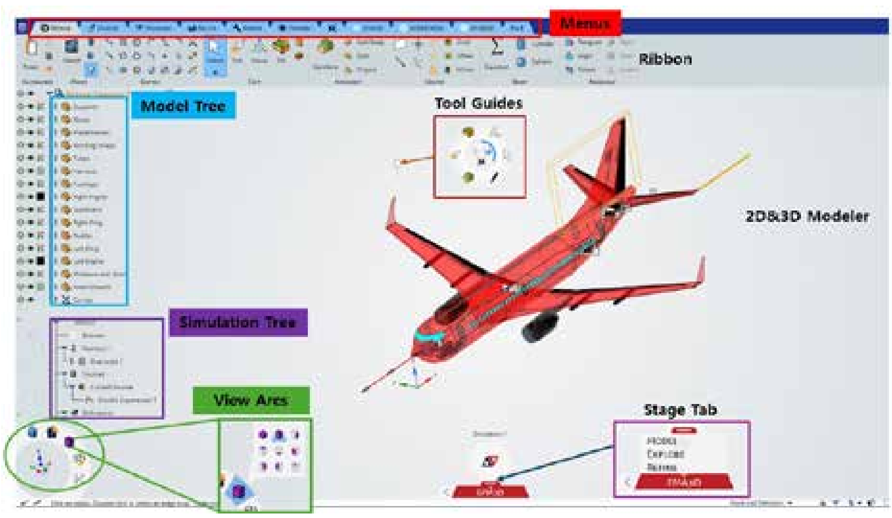


Fig. 2. Ansys EMC Plus GUI.

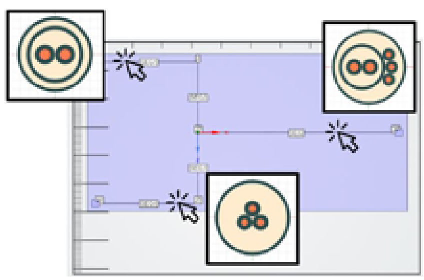


Fig. 4. Cross sectional view of a cable harness.

simple. Just select a line and click on "cabling" to choose the desired type of cable, and the configuration is complete. Ansys EMC Plus boasts significant advantages that existing users can access quickly and easily using the Discovery GUI.

Figs. 3 and 4 illustrate the available cable types and configured cable cross-sections, respectively. This user-friendly approach to harness cable modelling in Ansys EMC Plus, coupled with its intuitive interface, contributes to a seamless experience for both new and experienced users, making it an efficient tool for cable system analysis and simulation.

2) Source and probe

Source and probe configuration is essential for correct cable analysis. The term "source" refers to the signal input to the cable and encompasses pin voltage, pin current, and differential voltage. To extract and examine the analysis results, probes must be set up. The configuration of probes is essential for verifying the result. In this article, crosstalk between cables was extracted using pin voltage, while the boxed region was used to determine the leaking electric field (e-field). Fig. 5 contains an illustration of the source and probe configuration.

3) Mesh and simulation run

The final steps of cable analysis include mesh generation and the simulation run process. Ansys EMC Plus simplifies mesh creation with just a single click on the "mesh" button. Fig. 6 illustrates the automatically generated mesh. Starting the simulation is as straightforward as clicking the "start" button, which initiates the analysis. Fig. 7 shows a graph of the analysis results.

Conclusion

In this paper, cable interference was analysed using Ansys EMC Plus. Ansys EMC Plus facilitates simple configuration of harness cables allowing existing Ansys users to take advantage of its ease of use thanks to the Discovery GUI.

About TSNE

Since its establishment in 1988, TSNE has specialized in CAE, providing engineering programs and services to Korean customers. Tae Sung S&E (TSNE) aims to be the "One Stop Total CAE Solution Provider" (OSTS) both in domestic and global markets. The company leverages its large base of business capabilities and its team of CAE experts to provide services to customers in various industries (aerospace, automotive, civil engineering, biomedical, shipbuilding, electrical and electronics, energy, defence, chemical industries, etc.) and is expanding its business scope to research innovative technologies and apply them in the field. It strives to become a global engineering company and increase its potential as a sustainable engineering company. Tae Sung S&E partners all engineers who endeavour to solve challenges. Tae Sung S&E will work with you to achieve "NO PROBLEM, BE HAPPY".

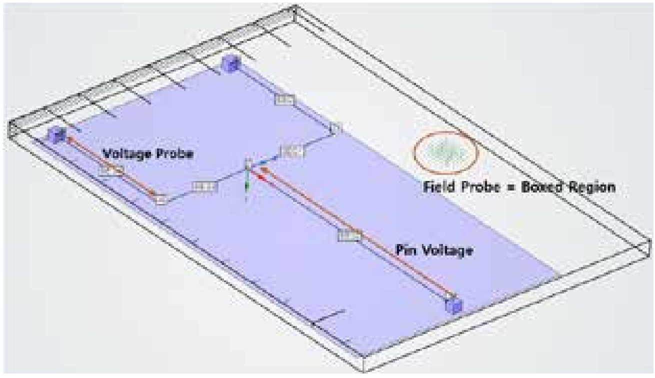


Fig. 5. Source and probe.

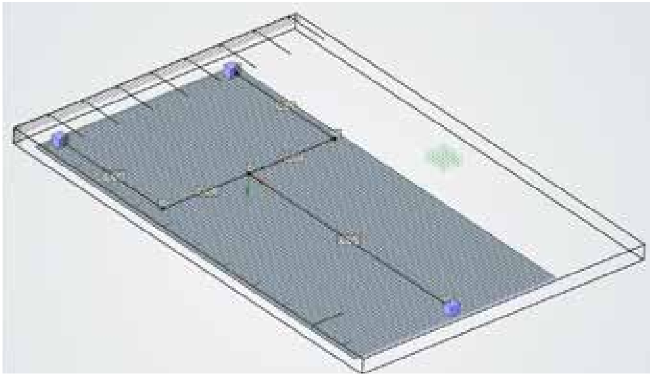


Fig. 6. Mesh.

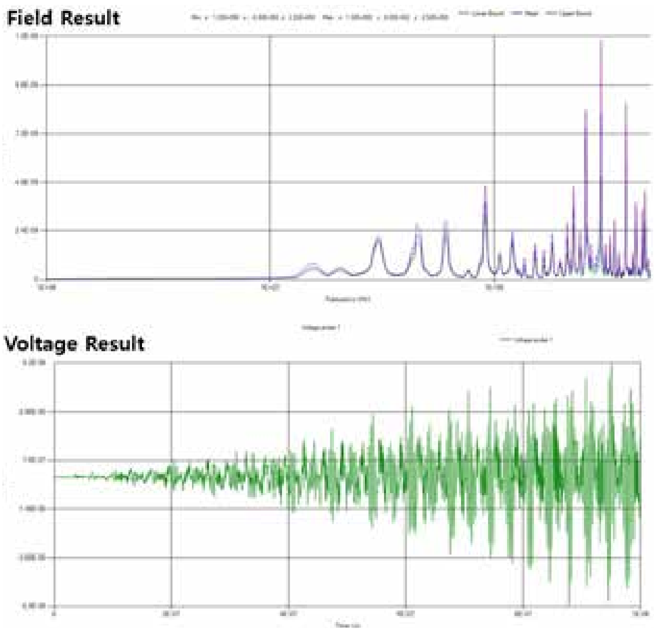


Fig. 7. Simulation result.

For more information:
Dae Hyun Kim - Tae Sung S&E
dhkim@tsne.co.kr

EnginSoft celebrates a milestone of 100 research projects and continues its commitment to innovation

EnginSoft's commitment to collaborative research and innovation projects has achieved an ambitious goal: in 2023 we reached 100 research projects (national and European) in which we were involved as partners or coordinators. There have been enormous spin-offs for the company – from the development of new methodologies and technologies, to the business network and relationships that have been established, as well as the skills we have acquired, increased and shared in areas that add great value and have truly international scope.

As a company, proud to be at the forefront of innovation, we will certainly continue to invest in this pillar which even now, at the beginning of 2024, sees us continue to play a leading role in new projects spanning very different sectors.

Among the European initiatives we have joined, the "newest" additions are:

- **BioStruct**: which will develop an innovative manufacturing process for bio-based fibre-reinforced composite parts for structural applications;
- **ACCURATE**: which aims to achieve resilience through manufacturing as a service, digital twins of manufacturing systems, and ecosystems;
- **ODE4HERA**: the Open Digital Environment for Hybrid-Electric Regional Vehicles project; and
- **YOGA**: which, and as the full title "Your Osteoarthritis Goes Away" says, will focus on tests of new personalized treatments for osteoarthritis

For more information:
Carla Baldasso – EnginSoft
c.baldasso@enginsoft.com

BioStruct

Manufacturing process for bio-based fibre-reinforced composite parts for structural applications

The BioStruct project is committed to developing high-precision manufacturing processes for bio-based, fibre-reinforced composite parts for structural applications. With a budget of €8m over three years, BioStruct brings together ten partners including end users and partner companies in automation, machine building, measurement technology, material manufacturing, and simulation software to comprehensively cover all aspects of development.

BioStruct aims to address the challenges currently associated with the use of bio-composites in structural components and to broaden the scope of applications for bio-composites.
Its specific objectives and corresponding actions include:

- Developing an accurate draping process to control fibre orientation
- Creating material models to capture natural variability
- Integrating nano-structured, bio-based sensors for load monitoring

The project aims to achieve predictable properties and consistent quality through enhanced accuracy and additional control loops in the manufacturing process. It will demonstrate these advancements through two distinct use cases focusing on wind energy and boat-building that will prove the effectiveness of these innovative manufacturing technologies. In this project, EnginSoft is responsible for the simulation of the manufacturing phases of the bio-based composite, such as draping and curing, including the calibration of virtual models through experimental verification. Then EnginSoft will be responsible for structural verification and optimization of the maritime components. And, finally, for creating the Life-cycle Assessment (LCA) data inventory and estimating the economic and environmental impact of the newly developed process.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101092073

ACCURATE

Achieving resilience through manufacturing as a service, digital twins, and ecosystems

The ACCURATE project aims to boost the competitiveness of European manufacturing companies and value chains by improving their sustainability, performance stability, resilience, and ability to manage unforeseen events.

ACCURATE will develop innovative approaches and deliver an integrated set of results culminating in:

- a human-centric Decision Support System (DSS) offering a better understanding of the impact of unforeseen events on manufacturing and industrial networks, providing timely, optimal and robust manufacturing supply and value chain design, planning, stress testing, reconfiguration, and recovery and improving circular and sustainable performance;
- a Manufacturing-as-a-Service (MaaS) framework covering multiple critical supply and value chains, leveraging data-space technologies as well as multi-scale and multi-level Digital Twins and co-simulation in order to deliver swift adaptation capabilities for logistics and production that are technically and economically viable;
- an open, standards-based, federated and trustworthy data space and ecosystem that integrates data flows, models, and tools across actors in manufacturing value chains thereby creating smart manufacturing networks and empowering humans and organizations to share valuable information and collaborate on MaaS solutions while retaining full sovereignty over their sensitive data and intellectual property.

ACCURATE's results will be validated through three pivotal use cases covering multiple key European industrial sectors and value networks: aerospace, automotive, biotech, energy, medical, and mobility.

The participation and commitment of industrial partners like Airbus, Continental and TRONICO underlines the project's viability. The ACCURATE project will exploit the transformative potential of data spaces and ecosystems in revolutionizing business models and value propositions, and will leverage these technologies and approaches to achieve impact, create resilient manufacturing networks, instigate deep innovation, and accelerate the adoption of results.

EnginSoft is the scientific coordinator of the project and is also responsible for the design and development of ACCURATE's human-centric DSS. To this end, the company provides its expertise in data analytics and data modelling applied to manufacturing processes and will develop data- and simulation-driven digital twins at process/system-level. Additionally, EnginSoft will implement the modelling of unforeseen disruptive events and multi-level analysis of the propagation of cause and effect on supply chains.

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101138269

ODE4HERA

Open Digital Environment for Hybrid-Electric Regional Architectures

The objective of the ODE4HERA project is to enable and accelerate the development of Hybrid-Electric Regional (HER) aircraft through improved tools and techniques implemented in a transferable and Open Digital Platform (ODP).

The project, coordinated by DLR, involves the largest international players in the sector, including Airbus and LEONARDO. HER configurations contain far higher complexity than conventional configurations and involve new aircraft technologies and broader collaboration across the value/supply chain. The Open Digital Platform developed in ODE4HERA will combine Model-Based System Engineering (MBSE), Multi-Disciplinary Optimization (MDO), Simulation Data Management (SDM) and Product Lifecycle Management (PLM) technologies and extend them with novel open interfaces, formats, and smart model and data transformation technologies to efficiently handle and process the complexity of HER configurations.

The ODE4HERA project will introduce four innovations:

- a comprehensive and industry-ready open data platform tailored to the unprecedented level of complexity of HER configurations;
- full interoperability across the entire HER value/supply chain;
- tracing and checking the complex models and mapping them to the huge amount of data generated during the HER development process by different organizations using different tools;
- use of certification guidelines for software development

EnginSoft will implement the MDO both for CAE (Computer-Assisted Engineering) and for MBSE, which is increasingly required in the application of Integrated Verification and Validation (IV&V). In addition, EnginSoft will develop the PLM and SDM interfaces that are crucial for the automation of workflows to ensure the digital continuity of enterprise.

This project has received funding from the European Union's HORIZON JU Innovation Actions under Grant Agreement No. 101140510

YOGA

Miniaturized cartilage-tissue culture wells for point-of-care diagnosis and personalized treatment of osteoarthritis and Your Osteoarthritis Goes Away

Osteoarthritis is a widespread disabling condition among the elderly. YOGA is the first step of a broader pathway that aims to find personalized therapies by coupling in vitro diagnostics and artificial intelligence. In YOGA, a complex cell culture system will be developed to simulate cartilage tissue for use with biopsies in a physiological, proinflammatory and hydrogel-treated regenerative environment.

The concentrations of inflammatory markers will be measured using EliChip, a microfluidic platform from Trustech, and the concentration of nitric oxide with a specially developed Lab on Chip (LoC). The results will be archived and standardized in a specially created database for future developments aimed at diagnosis and personalized medicine. Sensitivity analyses on data from the laboratory environment will be performed to study the behaviour and relationships between tissue and therapeutic characteristics in order to develop a model that can replicate in vitro experiments and predict the efficacy of a therapy.

YOGA's goal is to create a semi-automated and standardized platform that can be used in any clinical laboratory to characterize tissue by biopsy when very little material is available. The application to osteoarthritis aims to provide a comprehensive, versatile and scalable model that can be easily adapted to other diseases. The innovation is the integration with the digital platform to host and analyse large amounts of data through advanced machine learning algorithms.

EnginSoft's contribution is focused on implementing a user-friendly platform based on machine learning algorithms for the predictive and personalized medicine) and on modelling the micro-fluidic behaviour of the EliChip.

The YOGA project has received funding from the Cascade funding calls of the NODES Programme, supported by the MUR - M4C2 1.5 of the PNRR funded by the European Union - NextGenerationEU Grant agreement No. ECS00000036.

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