Experience of Designing Natural Gas Transmission Pipelines in Super Challenging Geological and Environmental Conditions of Eastern Siberia and the Far East

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In 2011, pursuant to the order of the Russian Federation Government, OAO Gazprom successfully put on stream the **Sakhalin – Khabarovsk – Vladivostok gas transmission pipeline**, which is part of the future integrated gas production, transmission and supply system in Eastern Siberia and the Far East, taking into account potential gas exports to China and other Asia-Pacific countries.

This project is the first gas transmission project implemented by OAO Gazprom as part of the **Eastern Gas Program** and intended for gas supply to consumers in the Sakhalin Oblast, Khabarovsk and Primorye Krais as well as for Russian natural gas deliveries to the Asia-Pacific markets. The main goal of the gas pipeline construction is shaping an efficient gas industry in the region and establishing prerequisites on this basis for the rapid socio-economic development of the Far East and substantially better living standards of the regional population.

A crucial impeding factor for the project implementation was a tight design, engineering and construction schedule in view of the need to start feeding gas from September 2011 to infrastructure facilities in Vladivostok and to the Russky Island as part of the preparations for the APEC 2012 Summit. It took around three years from the commencement of the design and survey work to launch the first start-up complex in September 2011. The projected length of the Sakhalin – Khabarovsk – Vladivostok pipeline is 1,836.7 km (including 1,227.6 km of the first start-up complex), outer diameter – 1,220 mm, operating pressure – 9.8 MPa. The pipeline comprises 14 compressor stations (at full capacity), a submerged two-line crossing under the Nevelsky Strait and a gas branch to Vladivostok with the length of 116 km and nominal diameter of 1,000/700 mm (Fig. 1).

Fig. 1. Basic Characteristics of Sakhalin – Khabarovsk – Vladivostok Gas Transmission Pipeline

The gas pipeline route is characterized by the unique natural & climatic, engineering & geological, seismotectonic and environmental conditions, including by:
• a high seismotectonic activity: it crosses 56 tectonic faults, of which 16 are active, includes a total of 112 km of sectors with the seismic activity in excess of 8 degrees;
• a highly vulnerable unique natural & environmental system of the Far Eastern region: it traverses 14 specially protected natural areas, such as the federal Anyuisky and Leopardovy wildlife reserves;
• significant hydrographic and ravine/draw relief dismemberment (the route passes via 734 watercourses, 325 draws and ravines, runs more than 300 km through waterlogged patches and swamps);
• construction of a submerged crossing (two lines, 22 km each) under the Nevelsky Strait between the Sakhalin Island and the mainland.

In addition, a special mention should be made of:
• complex and highly variable geologic and lithologic structures;
• plots with close bedding of rocks and metamorphic formations;
• a high activity of erosion and suffosion processes as well as gullying;
• substantial development of lateral and vertical erosions of river valleys.

The pipeline route was chosen and site facilities were deployed with consideration for territories and objects with a restrictive and specific type of environmental management (specially protected natural areas, historic & cultural territories and objects, water conservation and forest protection zones, coastal protection stripes, high-value forests and woodlands with high-value species, specially protected plants and animals, extra valuable landscapes and biotopes, spawning areas and fishing places).

During the construction of watercourse crossings the project stipulated measures aimed at mitigating direct and indirect losses of fishery and potentially fishery hydrobionts. In addition to the conventional pipelaying schemes, the project provided for trenchless pipelaying by directional drilling under some water streams. Underwater operations at rivers with high fishery potentials were carried out in the wintertime. Taking into consideration the unique features of the pipeline route, its design and construction were implemented in compliance with the requirements for hazardous facilities. To that end, engineering solutions were developed so as to guarantee the gas transmission pipeline integrity and reliability under extreme seismotectonic conditions (Fig. 2).

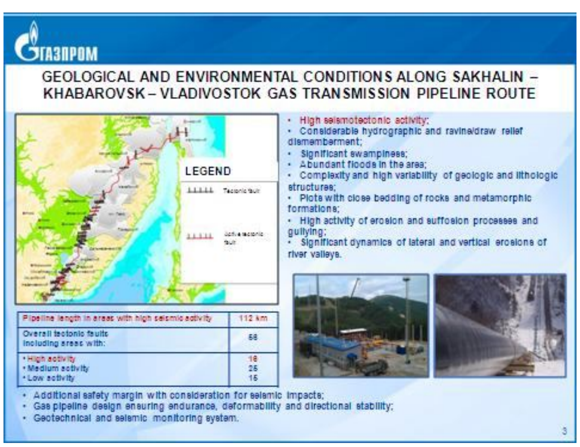

Fig.2 Geological and Environmental Conditions along Sakhalin – Khabarovsk – Vladivostok Gas Transmission Pipeline Route

In particular, the seismic shock resistance of the pipeline is secured by:
- additional pipe strength redundancy based on would-be seismic effects;
- engineering design schemes guaranteeing endurance and ruggedness of the pipeline;
- deployment of a geotechnical and seismic monitoring system.

A set of engineering solutions was designed for passages through active tectonic faults. These solutions include the implementation of dedicated pipeline steel, specialized pipeline and trench design, specific construction and installation methods as well as the deployment of a system of continuous geotechnical monitoring.

Specific engineering solutions in areas of crossing tectonic faults include (Fig. 3):
- selection of dedicated mechanical properties of pipe steel and its nominal dimensions with consideration for soil deformations and a type of mechanical displacement;
- pipeline horizontal and vertical turns by elastic bending with the radius no less than 1,500DN;
- dedicated configuration of the trench at tectonic fault crossing and at 100 m to both sides of the crossing, which secures minimum pipeline pinching, prevents soil congelation in the wintertime and provides for possible horizontal shifts;
- limitation of a pipeline laying depth;
- rock placement and backfill of the trench by loose soil (coarse-grained sand, fine gravel);
- a fiber-optic system of continuous geotechnical monitoring;
- engineering and construction of the pipeline in zones with tectonic faults based on the Special Technical Specifications developed and approved in due order.

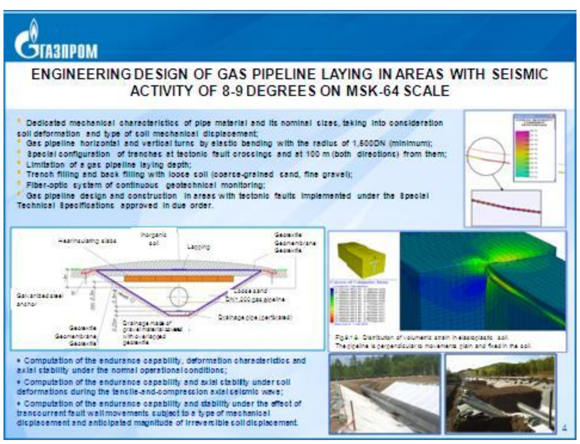

Fig. 3 Engineering Design of Gas Pipeline Laying in Areas with Seismic Activity of 8-9 Degrees on MSK-64 Scale

Technical requirements for pipes laid in areas with tectonic faults were developed with due account for the international experience of gas transmission facility construction in active seismic zones. Based on these requirements, pipes with high deformational characteristics were used.

In computing the endurance capability of pipes in areas with tectonic faults with the use of specialized software packages not only static forces were considered, but dynamic loads from single act soil displacements and elastic properties of pipe metal were taken into account as well.

A set of computer models includes:

• computation of the endurance capability, deformation characteristics and axial stability under the normal operational conditions;
• computation of the endurance capability and axial stability under soil deformations during the tensile-and-compression axial seismic wave;
• computation of the endurance capability and stability under the effect of transcurrent fault wall movements subject to a type of mechanical displacement and anticipated magnitude of irreversible soil displacement.

The site facility location was selected in areas most appropriate from the standpoint of minimizing seismic impacts on equipment and communications. This selection excludes the presence of tectonic faults in these areas.

Dedicated engineering design of pipeline configuration and topology, antiresonance and stress-relief supports as well as specific requirements for seismic resistance of applied equipment were developed so as to secure the seismic resistance of aboveground piping of compressor stations, gas metering and gas distribution stations, pressure reduction units (Fig. 4).

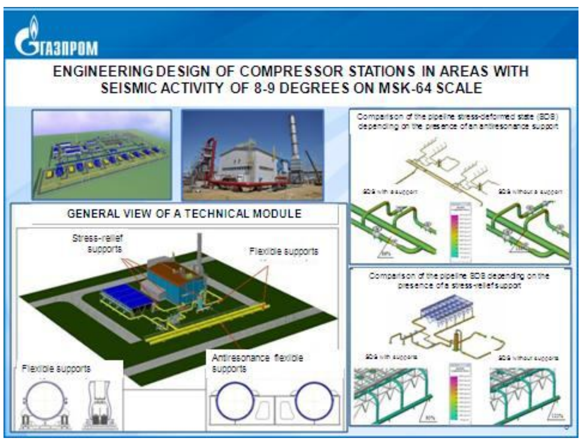

Fig 4. Engineering Design of Compressor Stations in Areas with Seismic Activity of 8-9 Degrees on MSK-64 Scale

In order to reduce seismic loads and enhance the compensating potential of connection piping every major pipeline was designed and constructed using compensators of axial movements. All piping is laid without rigid attachment to facility walls or machinery. Pipeline ingresses into facilities are ensured through apertures which are more than 200 mm wider than the pipeline diameter.

The design of aboveground pipeline supports provides for pipeline movements during earthquakes. Compressor piping is equipped with supports which are fitted with force measurement sensors and are regulated to adjust force interaction of a support with the pipeline.

Each support span has an aboveground pipeline pulsation damper guaranteeing unrestricted pipeline movements in case of changes in the pipe temperature and the pressure of conveyed products.

The thickness of pipe walls and fittings was determined in compliance with the construction standards of Russia and OAO Gazprom, taking into account an additional strength margin.

Calculations of the pipeline stressed-deformed state (SDS) at compressor stations located in earthquake zones were carried out during the engineering design of pipelines using antiresonance and stress-relief supports in comparison with conventional solutions. The use of dedicated supports results in the SDS reduction by 20-27%.

The project also provides for indispensable earthquake-proof measures during the engineering design of pipe foundations, connections with grillage, building frames, wall and roof enclosing structures.

For the sake of operational safety a unique technical status monitoring system is in place at the gas transmission pipeline. This system is an integral part of the industrial/environmental monitoring complex. The monitoring package comprises several subsystems (Fig. 5) including:

- a seismic monitoring subsystem (6 stations covering some 120 km of the pipeline);
- a geodeformation (geodynamics) monitoring subsystem comprising 89 GPS receivers deployed in landslide areas and at tectonic fault boundaries;
- a geotechnical monitoring subsystem based on fiber-optic sensors supervising 94 km of the pipeline on the Sakhalin Island (including active tectonic faults) and 29 km of active tectonic faults in the mainland;
- a geotechnical monitoring subsystem based on “smart inserts” supervising 46 potentially unsafe areas of the pipeline.

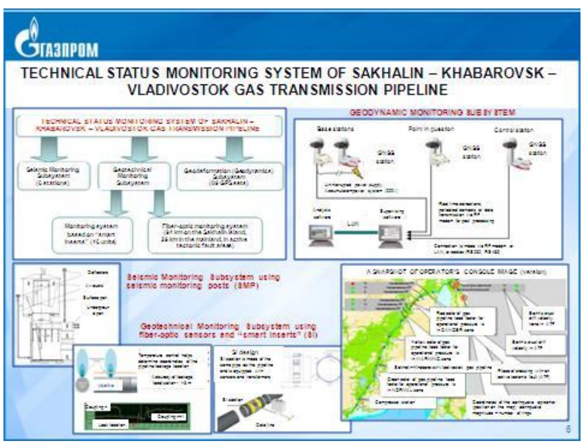

Fig 5. Technical Status Monitoring System of Sakhalin – Khabarovsk – Vladivostok Gas Transmission Pipeline

The seismic monitoring subsystem has the following tasks:

- monitoring and registering geomechanical (seismic) processes and an activity level of tectonic faults in a real-time mode;
- transmitting information for decision making on safe pipeline operation and incident mitigation.

Along with that the following parameters are identified: coordinates of seismic events which determine the seismic source localization and the event occurrence time, the seismic event energy related to the dynamic characteristics of an earthquake source.

In order to monitor the SDS of the Earth’s surface a network of telemetry seismic stations is under consideration. This network will be comprised of:

- a seismic monitoring post – an underground bunker accommodating a set of equipment (seismic sensors, registration devices, indicators);
- a data storage and processing server in a regional control center.

The geodynamics monitoring subsystem provides for continuous registration of vertical and horizontal shifts of the Earth’s surface using measurements of

GPS/GLONASS/Galileo receivers located in potentially unsafe areas: active tectonic faults, hillsides, landslides, washing-outs, etc.

The tasks of the geotechnical monitoring based on fiber-optic sensors installed at crossings via tectonic faults and in areas with seismic activity in excess of 8 degrees are as follows:

- continuous measurement of axial deformations and oscillating motions of the pipeline with geographical reference;
- control over deformations of the soil surrounding the pipeline;
- generation and transmission to a control center of an alarm information in case of the overrun of predetermined threshold values of axial deformations and pipeline oscillating movements.

At the same time, the subsystem enables to identify leak/damage locations by using the embedded function of temperature monitoring.

Based on the “smart inserts” the geotechnical monitoring subsystem provides for:

- measurement of pipeline mechanical tensions with the help of measurement sections which are pipe sections with six affixed strain-gage sensors distributed evenly over the cross-section of the pipe in 60º increments;
- transmission of information from “smart insert” control points to the “smart inserts” monitoring system server which is deployed in the regional control center;
- formation of on-line archives within the “smart inserts” monitoring system server, generation of warning and alarm signals;
- computation of the pipeline endurance margin.

All the information is uploaded through telemetry communication channels to an automated working station of the geotechnical monitoring subsystem operator. This enables to achieve:

- visualization of every process within all monitoring subsystems at a single console;
- integration of subsystems into a single network;
- information interchange with other systems;
- regional control center operator notification in case of the overrun of predetermined threshold values;
- creation of a monitoring data base.

A snapshot of the operator’s console image is shown in the figure.

In parallel with the construction of the Sakhalin – Khabarovsk – Vladivostok gas transmission system a unique project for gas deliveries to consumers on the Russky Island was implemented: a **gas distribution pipeline from the Vladivostok gas distribution station.** The pipeline length is some 31 km, of which 2.8 km run under the Eastern Bosphorus Strait (Fig. 6).

A two-line submerged 426 mm crossing was constructed by two directional drilling rigs stationed in the mainland and on the Russky Island and pushing their way towards each other.

The crossing of such length, diameter and depth (142 m downwards from the surface entry point) was constructed under the complicated soil conditions (rocks and half-rock soil of high cleavage with heaving seams of rock debris, intrusions of big stones and other large-size debris) for the first time in the world practice.

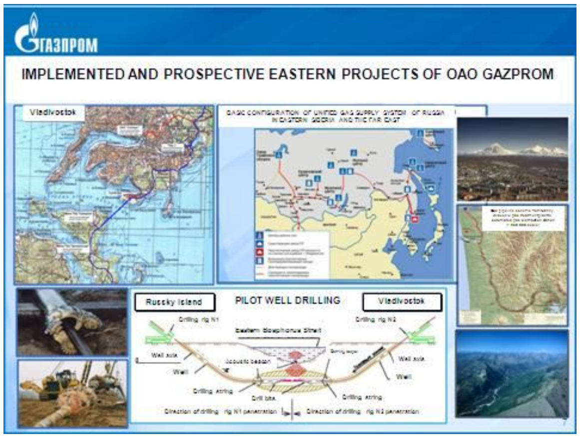

Fig 6. Implemented and Prospective Eastern Projects of OAO Gazprom

In September 2010, pursuant to the Russian President's order, OAO Gazprom successfully brought on line the **Sobolevo – Petropavlovsk-Kamchatsky gas transmission pipeline.** The pipeline with the length of some 400 km laid the foundations for gas supply to and gasification of Petropavlovsk-Kamchatsky and other population centers on the Kamchatka Peninsula. The unique characteristics of this regional project are a high seismic and tectonic activity and one-of-a-kind natural & environmental system of Kamchatka where most rivers and streams crossed by the pipeline (over 380) have the utmost commercial fishing importance.

The experience gained during the design and construction of the first projects of the Eastern Gas Program successfully implemented by OAO Gazprom in such a short time will be solicited for during the implementation of another large scale project – the creation of the Yakutia gas production center based on the Chayandinskoye gas field and, first and foremost, when designing the **Yakutia – Khabarovsk – Vladivostok gas transmission pipeline**.

The complexity and unique characteristics of the projected pipeline with the length of some 3,000 km to a connection point with the Sakhalin – Khabarovsk – Vladivostok pipeline in the vicinity of Khabarovsk pose extremely high requirements for technological and engineering solutions.

The extreme natural & climatic conditions (the absolute minimum of ambient temperature of -61º C), extended areas of permafrost soils, dangerous geocryological processes (erosive action, thermokarst, rockslide, landslides, coombe rocks, solifluction, ice crusts, erosions, suffosions, seasonal soil heaving), seismicity above 9 degrees, a plenty of tectonic faults, a complicated surface profile with heights of up to 1,500 m, swamps, specially protected natural areas, multiple crossings with large water basins, lack of developed transportation infrastructure and necessary manpower – all this requires a special approach to searching for unconventional design solutions so as to secure the technical integrity, economic efficiency and environmental safety of the project.