Scientific and Engineering Support of Design and Construction of Gas Industry Facilities as a Factor in Reducing Investment and Construction Risks

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The huge experience of pipeline design and construction in the USSR provided grounds for establishment of a regulatory framework that facilitated successful implementation of oil and gas projects (government and administrative construction regulations). However, a large part of these regulatory requirements rests on empirical data collected in 1960s–1980s and the construction methods of those times.

There is an opinion among builders that nothing has fundamentally changed in the past 40 years in either pipeline design or construction. However, this is far from being the case: dramatic changes took place practically at all stages of the investment cycle. This is primarily due to an increase in the technical level of materials, equipment, and technologies used in the oil and gas industry; and major economic, organizational, administrative, and social transformations.

The past decades evidenced enforcement of requirements in the legislation shaping the governmental environmental protection and safety policy [1].

The typical feature of the modern Russian oil and gas projects is that hydrocarbon reserves are developed in completely new, extremely harsh natural and climatic conditions, that are in some cases unique in terms of severity, such as the Arctic territory, the Arctic shelf, Eastern Siberia with its record-breaking frosts, etc.

According to the Ministry of Industry and Trade of the Russian Federation, today's pipe industry is the most technology intensive branch of metallurgy with more than 500 billion rubles investments during the last 20 years. These funds have been aimed primarily at improving the product competitiveness and bringing it to international standards. As a result, the share of high-tech pipes has increased from five to 60 per cent [2].

The high engineering level of pipe works empowered PJSC Gazprom to retarget its business towards creating a new generation of trunk pipeline systems characterized by higher operating pressure, longer distance between compressor stations, and therefore increased wall thickness and bending stiffness.

New welding and trenchless methods, use of pipes with factory insulation, an extensive use of synthetic and composite materials, increased specific performance of gas compressor stations – this is by far not a complete list of engineering innovations that have become widespread in the industry during the recent years.

At the same time, the design and construction methods are significantly lagging behind in their development. As an example, we can cite the main documents for the design and construction of trunk oil and gas pipelines, such as code of rules SP 36.13330.2012 and SP 86.13330.2014. Despite the fact that these codes of rules are updated versions of SNiP 2.05.06-85* and SNiP III-42-80* respectively, their key provisions have hardly undergone any significant change, being based on the fifty-year-old level of knowledge.

The modern investment cycle for creating oil and gas facilities implies significant reduction in the construction time. This is due to the volatility of the global prices for hydrocarbons, the need to reduce the credit burden, etc. On the other hand, linear construction, which extends over large territories, is characterized by meteorological dependence of some technologies. Thus, construction on permafrost soils is often impossible during the warm season, whereas pipeline hydraulic testing at large site facilities, on the contrary, is much more complicated and expensive in winter. Therefore, a relatively small delay in performing intermediate works can lead to a critical rescheduling of the facility commissioning.

It means that building of oil and gas facilities requires strict adherence to the planned schedule, which must take into account construction, supply and risks. It should be noted that foreign oil and gas projects carefully consider risks at the stages of design and construction planning [3]. Then, the technical customer makes a decision on the preventive preparation of remedial measures to eliminate the impact of risks on construction deadlines. Domestic requirements for design and estimation documents set a rigid timeframe that does not allow for including backup activities in the documents.

A rather difficult situation is observed around trunk gas pipeline facilities design. Almost all calculation methods have been conceptualized to the maximum and adjusted to calculations with a slide rule or, as a last resort, an engineering calculator. However, the adopted calculation schemes in many cases have nothing to do with an actual state of things. For instance, calculations related to the pipeline stability in the ground (to prevent its floating up) are performed according to Archimedes' law, despite the much more multifactorial mechanics of the interaction between the pipeline and the soil. The schemes were simplified as much as possible to perform calculations using the available tools. Thus, pipeline stress-strain state calculations and the load on pipe layers are algebraically feasible only for three suspension points (Fig. 1). This was justified for the large-scale construction of trunk pipelines in the 70s–80s of the last century, and is unacceptable for qualitatively new trunk pipelines that are currently under construction and for applied innovative solutions. The attempts to handle modern computer technologies are hampered by a sophisticated mathematical description of basic physical processes, especially those related to soil physics.

Figure 1 – Placement of pipelayers in groups due to the specifics of calculations performed at three suspension points.

Due to these facts, a whole range of requirements contained in the updated regulatory documents is unsuitable for modern conditions. The use of new pipeline anchor designs in Russia is a striking example of the described problems, despite the fact that such anchors have been widely used for several decades in the North America. It turned out to be very difficult to update these requirements in the absence of correct physical and mathematical models.

The practice of modern large investment processes has shown that each stage where there is a need for an optimal engineering solution requires a sophisticated and highly professional scientific and analytical work.

In particular, specifics of oil and gas facility construction is an exceptionally large scope of earthworks and hidden works. In this regard, the interaction of soil with underground structures has a critical impact on the quality of structures.

Surprisingly, big problems are observed not so much in the Far North, where permafrost is widespread, and in deserts composed of dry sand, but in the northern regions where the soil has time to dry and moisten, freeze and thaw again to a great depth during 4 seasons (Fig. 2). It was the need to build pipeline transport facilities in such regions that Soviet designers and builders encountered during the development of deposits in the Western Siberia. Their experience served as the basis for the requirements of SNiPs and administrative construction regulations (VSN), whereas design and construction were supported by the industry research institutes.

Figure 2 – Results of uncontrolled pipeline subsidence after soil thawing.

Very often, the design and construction experience available at the time of regulatory documents development could only reveal a problem, but did not offer any solution to it due to poor understanding of the causes of the phenomena observed. In these cases, in regulatory documents that establish requirements for design and construction, we can find provisions such as "carry out the calculation according to the rules of structural mechanics" or "take into account a number of loads", which cannot be done in practice without understanding the causes of the problems. Here is an example of this kind of problem.

In the standard engineering requirements for designing site facilities [4], there is Paragraph 7.5.3: "Generally, all underground pipelines with a diameter of 500 mm and more require supports on a pile foundation". Such a requirement could have appeared only after a series of incidents related to deformations of the surface parts of pipelines caused by movements of related underground sections. However, no calculation methods are given in the document. In fact, it proposes to "calculate using the rules of structural mechanics".

The design institute made calculations, designed the supports, and there were no problems on more than a dozen of constructed facilities. Meanwhile, at two facilities, supports installed on pile foundations withstood the load, but not the pipeline itself.

The analysis carried out by Gazprom VNIIGAZ LLC has shown that the reason for such high loads on supports was the subsidence of soil under the pipeline that thawed in summer after winter construction (Fig. 3), which had not been taken into account in the calculations. The facilities with no problems had been constructed during the warm season.

Figure 3 – July: ice underneath the exposed pipeline laid in winter is removed.

Unfortunately, in the domestic design practice, it is not customary to have backup design solutions dependent on the construction season. Meanwhile, the reason for introducing the above requirement was just the great mobility of underground pipelines after winter construction, resulting in deformation of the related surface pipelines installed on their own pile supports. After the reasons for the accident became clear, the problem was easily solved using the methods of calculating continuous beams and elements of underground structure mechanics.

This example shows that the scientific analysis of the identified problems can have a significant effect, if not at the facility where scientific and engineering support for construction was provided, but at least at the facilities constructed afterwards.

"Scientific and engineering support for construction (SESC) is a set of scientific, analytical, methodological, informational, expert control, and organizational activities carried out by specialized organizations in the process of survey, design, and construction to ensure the construction quality, reliability (safety, functional suitability, and durability) of buildings and structures, taking into account the applied nonstandard design and engineering solutions, materials, and structures" [5].

In this regard, SESC addresses only those issues that cannot be resolved unambiguously by applying the provisions of the current regulatory documents. "Scientific and engineering support does not duplicate existing forms of control, but only effectively supplement them through the use of special means, instrumental and laboratory tests, end-to-end control of the technical innovations, and generalization of experience for subsequent use" [6].

The initial problem was the difficulty in determining the scope of SESC. Almost all large-scale design institutes are equipped with the modern certified computer software applied in sophisticated calculations using the finite element method. This gives an impression that there are no obstacles for a modern designer in solving problems of any complexity. However, practice shows that things don’t look so trouble-free (see the example above).

Unfortunately, unresolved problems are usually revealed at the final stage of construction, when there is neither time nor resources to address these problems, whereas the time factor is decisive for oil and gas construction projects.

There are many examples of this kind, and they convincingly indicate that SESC should be systematic and widely deployed concurrently with the facilities design. At the same time, identification of specific problems, facilities, and the SESC itself should go in parallel with designing and construction.

The real effect from SESC is directly related to the experience and scientific qualifications of the involved specialists and teams, their creativity and the ability to stand their grounds in opposition to construction stakeholders. Insufficiently professional SESC, which a technical customer encounters, results in misunderstanding of the SESC functions perceived as a kind of primitive duplication of the research, design, and construction supervision activities, so that it is simply excluded from the scope of work with all that it entails.

As a positive example of the SESC effectiveness, we can cite the construction experience in modern Moscow, where almost since the 2000s we have seen rapid construction, including that of high-rise and large-span buildings. The capital has accumulated the maximum experience in the high-quality construction of unique buildings. During this period, the city has developed a regulatory and engineering support system for surveys, design, and construction, which facilitated fast and trouble-free erection of various structures. Providing scientific and engineering support in the course of construction is a mandatory requirement for creating complex structures in Moscow.

Apart from the Moscow construction projects, in today's Russia issues of scientific and engineering support have been examined in detail and regulated in important and rapidly developing nuclear and road industries, where the SESC practice proves to be highly effective.

At the same time, it would not be quite correct to believe that SESC guarantees the perfect quality of the facilities. The current state of engineering sciences is still very far from being ideal. Thus, there is still no credible theory describing the behavior of the soil under various effects and moisture. At the same time, statistical data accumulated during SESC helps to solve problems through implementing successful experiences. As stated above, generalization of experience for subsequent use is one of the most important functions of SESC, which can provide a tremendous effect in projects and certainly should be of interest to the technical construction customer.

For instance, during the construction of the Bovanenkovo-Ukhta trunk gas pipeline system, a fundamentally new approach to strength testing was implemented, namely, a widespread introduction of pneumatic tests, which facilitated testing in areas with permafrost soils and contributed to the timely commissioning of the facility. However, widespread introduction of the pneumatic test method has an impact on subsequent works during the pre-commissioning cycle, in particular, it affects efficiency of contaminants removal from the cavity of pipelines with a complicated spatial configuration. Gazprom VNIIGAZ research of the identified peculiarities performed in cooperation with Gazprom transgaz Tomsk LLC (Technical Customer) under SESC support of “The Power of Siberia” gas pipeline project revealed new technologies and facilitated implementation of the effective pre-start operations to provide high-quality preparation of the main gas pipeline cavity before its commissioning (Fig. 4). Such examples are rather common with a systematic approach to the SESC of new investment projects.

Figure 4 – Use of the "dynamic blowdown" method developed and implemented as part of SESC for cleaning the bypass piping of a linear valve assembly.

Given the state-forming role of the domestic oil and gas industry, it is critically important to generalize the successful experience of SESC in the implementation of investment projects. This will help to prevent possible errors, minimize the cost of their elimination, and reduce the time for putting facilities into operation.

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