MATHEMATICAL MODELLINGFOR OPTIMIZED PROJECT MANAGEMENT OF CONSTRUCTION OF LINEAR COMPONENT OFGAS PIPELINES PROJECTS

Sajjad Mubin*
Civil Engineering Department,
University of Engineering and Technology, Lahore, Pakistan
Corresponding author email: sajjadmubin@yahoo.comPh: 0322 8880003

ABSTRACT*: There is lack of infrastructure almost in every field in Pakistan, including rail, road, water supply, waste deposal and oil and gas transportation. Only 31 percent of the total population is utilizing the natural gas resources in Pakistan, due to unavailability of gas distribution system and adequate reserves of natural gas. Looking its high energy demand, Pakistan is planning to construct gas pipeline, importing cheaper natural gas from Iran. For construction of pipelines, conventional approaches of project management are being used which is not optimum, efficient and cost effective. Efforts have been made in this paper to optimize the construction process of linear part of pipeline with the help of mathematical model. Based on the model, a simplified methodology has been given efficient execution and control of linear part of gas pipeline projects.*

KEY WORDS: Construction, Gas pipelines, Modeling, Project Management, Risks

1. INTRODUCTION

Pakistan being a developing country is at the pace of progress. A lot of development is needed in almost every field to maintain a good infrastructure in the country to provide a comfortable, safe and economical living to the people. Construction sector is considered as hub of economic activities in the country because of its direct of indirect influence on economic growth. Process of development in a country is an equilibrium process for that the media is the world development and inputs are the world's resources. This process is being stabilized as the development is done at the same pace in the undeveloped countries as it is done in developed country. The stage of equilibrium will be attained when the development though out the world will be at the same pace. [1]

Construction is a part this cycle and considered most important element of this process. For the last ten years a significant growth has occurred in this sector in Pakistan during the last 10 years. It is also included in the government policies to rebuild and upgrade the total infrastructure of the country so that all people can enjoy same facilities and lifestyle throughout the country just like in the developed countries of the world. In developed countries the construction sector has reached at its mature stage. The major construction has been done in those countries from 60's to mid70's in which they provided a vast network of roads, hospitals, schools, water supply, gas pipelines and waste disposal system looking the forecasted need of each facility. At that time the research and development in construction sector was not so much advanced and they untilled the method and material of construction available at that time. Now the methods and materials used in construction have significantly changed due to the advancement in the research and technology. Now it is the time to utilize these state of the art techniques and technology in developing countries where a huge construction is going to occur.

In Pakistan the facilities and utilities of people quietly differ in different region. for example, still 40 percent population of the country are not having the one or more than one basic requirement like drinking water, hospitals, school, electricity and gas, and roads [2]. The resources and facilities are concentrated in the developed areas of the country like big or industrial cities. The system of resource distribution is unbalance and to balance this system there s a need of providing infrastructure like road network, water supply, sanitation, and gas pipelines network.

2. GLOBAL AND NATIONAL ENERGY SCENARIO

Global energy consumption is expected to increase steadily over the next twenty years. According to the International Energy Outlook 2001, the actual growth of the world energy consumption increased from 207 quadrillion Btu in 1970, to 382 quadrillion Btu in 1999. This, in turn, is anticipated to further increase to 607 quadrillion Btu in 2020. Quite remarkably, over this fifty year period, the consumption of energy is likely to increase by about 200 percent, from 207 quadrillion Btu in 1970, to 607 quadrillion Btu in 2020.Furthermore, the largest increase in energy use will occur in the developing world. From 1999 to 2020, energy consumption in the developing countries is expected to climb 122 quadrillion Btu, to 264 quadrillion Btu, demonstrating an increase of 116 percent. In other words, the increase in energy use in the developing world is roughly double than that of all countries in the global economy. This is because many developing countries are expected to fully develop their economies and become more industrialized.

Accompanying this process of economic development, additional energy will be required. Moreover, virtually all of the increase in the world's population, over the next twenty years will take place in the developing world. Population growth will add over 1 billion people to the poorer regions, thus expanding the energy requirements of these regions. [3].

In Pakistan during the last ten years 2000 to 2010, the consumption of petroleum products has increased by an average rate of 0.9 percent per annum. Pakistan is meeting only 18 percent of its oil need from indigenous production and the country had to import the remaining 82 percent and pay international prices. Similarly, 50 percent of the indigenous gas contributed a substantial portion of the energy requirements of the country. The energy mix in the form of sources of energy is given below for the year 2005-6 and 2012-13 (Table-1).[1, 4]

Table 1(a) and (b) Showing energy mix in Pakistan (%) year 2005-6 & 20112-13 (L/R)

Source of Energy	Share (%)
Natural Gas	51.0
Oil	29.0
Coal	7.5
Hydropower	10.8
Nuclear Power	1.3
LPG and others	0.4

Source of Energy	Share (%)
Natural Gas	44.0
Oil	29.0
Coal	10.0
Hydropower	14.0
Nuclear Power	2.0
LPG and others	1.0

3. GAS PIPELINE NETWORK OF PAKISTAN

Sui Northern Gas Pipeline Company (SNGPL) and Sui Southern Gas Company (SSGC) are mainly responsible for construction and operation of gas pipelines in the country. Operation includes selling, marketing and safe distribution of gas to the end customers. Construction includes construction of distribution network and main transmission pipelines. SNGPL is responsible for all operations in Northern part (Province of Punjab and NWFP) and federal capital and SSGC is responsible for its operations in southern part (Province of Baluchistan and Sind) of the country. The total network of main pipelines is almost 9,000 km (SSGNP share 6121km and SSGC share 2942km) and distribution network 70,000 km. In addition, SNGPL is expanding its transmission system by 1,045 km, increasing the network to 7,309 km. However, SSGC will add 608 km of transmission pipeline, expanding its network to 3,550 km by 2010 from 2,942 km this year. This will increase capacity to 1.7 bcfd by 2010 from the current 1.3 bcfd. SSGC also will add 5,236 km of distribution pipeline and supply mains, expanding its distribution system to 31,000 km by 2010 from 25,764 km this year and connecting 600 new towns and villages in Sindh and Baluchistan provinces. In the last 10 years SNGPL has completed 12 pipelines with the data given in table 2 along with their capacities.[5]. Current Industrial growth is demanding to find more sources of energy i.e. natural gas, which is cheaper and reliable. Therefore natural gas is also planned to be imported through pipeline from neighboring countries. Option of Turkmenistan, Iran and Qatar are available for gas import but Iran being at the top due to many geo-political and socio-economic factors. [6].

The construction of natural gas pipelines depends on many factors. One of the main objects of successful project management is to complete the project in time taking into account all factors which may delay project and precisely within budgeted cost and with in specified quality. But usually projects are delayed from their scheduled time. If the pace of work is increased then cost will be increased but the quality of work may be affected. If quality is maintained then we have to put more input (resources) in the form of money, manpower or machinery. The reason for diversion of actual construction from schedule is the internal or external factors or barrier. Internal factors may be the lack of expertise or resources, finance or inefficiency in one or more than one functions of the construction life cycle e.g. design not in time, material not in time, material not of quality, rework etc [7]. The external barrier may be the part of external environment of the organization. The most important factor in the Pakistani system of construction is the inefficient external organizational communication, regulations and delays in getting licenses and approval from provincial and federal government. SNGPL and SSGC are the functional organization in which the all stages of construction life cycle are executed internally. There is the interdepartmental relationship and coordination between these department (Design, Purchase and Administration, Project etc) to maximize the efficiency of work and to minimize the risk of project delay. Project team is specific to work rotationally on the different projects. [8].

Table 2: Completed Pipelines Projects from SNGPL in Pakistan in the last 10 years [5]

Pipe Segment	Available Capacity (MMCFD)	Max. Flow passed (MMCFD)	% age of existing Capacity Utilization	Capacity enhancement after Project-10 (MMCFD)
Sui- Bhong	790	681	86	790
Sawan- Qadirpur	370	275	74	1806
Qadirpur- Bhong	850	764	90	2140
Bhong -AC4	1630	1344	82	2060
AC4 - AV22	1590	1328	84	2230
AV22 - KotAddu	350	45	13	350
Dhodak - KotAddu	70	32	46	70
AV22 - Multan	1430	1265	88	1430
Multan - AV29	1350	1201	89	2160
AV29 - Sahiwal - Lahore	650	549	84	810
AV29 - Faisalabad	990	887	90	990
Faisalabad -Lahore	450	336	75	600

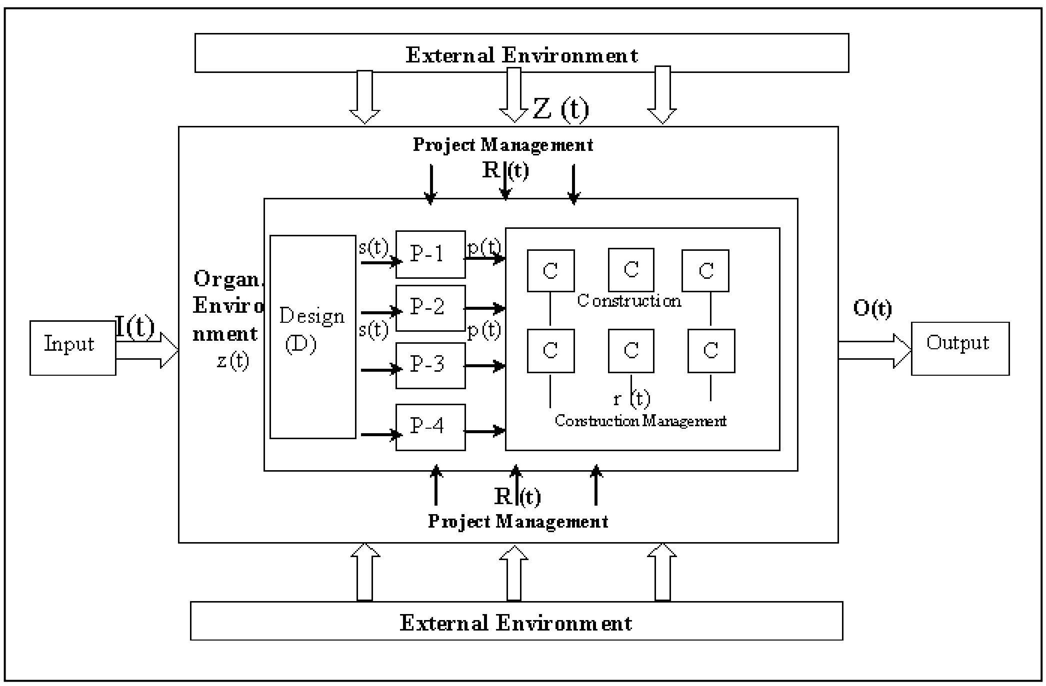

Figure 1. Model for construction process of gas pipelines project

4. MATHEMATICAL MODELING FOR CONSTRUCTION PROCESS OF GAS PIPELINES PROJECTS

The process of construction of gas pipeline is also just like an ordinary construction process functioning in an environment having Inputs I{t}(resources) process and output O{t} (pipeline) The model is developed in the figure-1, in which segmental approach has been developed with an incremental increase in volume of work. The successful development of model should result in;

1. forecasting and manage changes in internal and external environment of model or system;
2. optimization of construction process;
3. Effective decision making with effective results.

Therefore, the elements like Design (D), Purchase (P) and Construction(C) will be individual systems or processes happening in the organizational environment. The organization is functioning in external environment which is influencing the system by Z{t}. The project or set of projects executed in the organizational environment are governed by management of organization with R{t} to the system. The Sub-Model (sub-system) like Design, Purchase and Construction are managed internally with in the sub models with their own environment which function in organizational environment influencing within model s{t}, p{t} and c{t} respectively as shown in figure 1. Where "t" is member of $\{0, T_p\}$ where T_p is the project duration. The construction is a stream of interrelated sequential work packages which are connected to each other with logical relationships. The completion of the construction process in time is result of completion of these interdependent works in time though they have some time allowance (float) to complete them. The model becomes complex having many parameters. To make the model simple we have to make certain functions constant to optimize the process of construction. By making Input and Output constant we can optimize the system effectively. For example Time and end results can be fixed e.g. in "t" month with "y" rupees the "x" km pipeline can be laid.

$$S = \{[I, (D, R, E)|Z, N, G, \xi, T]O\} \quad \rightarrow opt \quad (1)$$

I={i} – Input resources, Information regarding project;

D={d} –Set of network elements of the system;

R={r} –Rules of the organization of system, legal and technological norms, specifications and method of project management;

E={e} –The stream of the information based on an available experience, professional knowledge and the statistical and operative data;

Z={z} –Set of factors of external environment i.e. social and economic influence;

N={n} –Set of natural climatic conditions in different zones of project;

G={g} –Set of ground conditions in which project is being executed.

ξ={ф} –Coordinate vector in space displacement;

T={t} –Vector of developed system in time;

O – System Output which can be give by following relation;

$$O: \{X(D, R, E)|Z, N, G, T\} \quad X, \quad (2)$$

Where, X-{x} - a target vector defining end product of modeled system since organizational-technological systems of pipeline construction are stochastic systems, therefore the target vector X will be achieved with probability P_J (Formula 3)

Case-1: for a discrete case

$$P\{X = X\,j\,|\,[I, (D, R, E)\,|Z, N, G, T], O\} = Pj \quad (3)$$

Where j = 1,2,3...

Case-2: for a case when, X has continuous function of F (x)(Formula 4)

$$P\{X < x\,|[U, (D, R, E)\,|Z, N, G, T], O\} = Pj = F(x.) \quad (4)$$

where $F(x) = \{F_1(x_1), \ F_2(x_2), \ldots\ldots\ldots F_N(x_n)$

Parameters of defined work changes during functioning of the system and depends on the characteristics of the parameters, functioning in the system. System is considered as continuous moving system with time (T) in one or multiple parameter space of conditions which is characterized by Eq. 5.

$$W = \{X, Z, N, G, T\} \qquad (5)$$

The expected change in the system, by enlarge or individually in the parameters of the system can be reacted by examining the target characteristic of system in particular space of conditions "W", the input of which are resources, the purposes, the historical and statistical information, the information on current status of the system and the previous experience of functioning the identical systems. The volume of the end production depends on the current status of the system for example the excavation work is completed at present time t. Consecutive transition of organizational-technological system from one condition to another i.e. movement of system in some direction. It means that current working or status of system reflects how system passes from current condition in some condition in the future? The following procedure is adopted for going into further details.

1. Selection of work package and their function in different conditions conducted in any gas pipeline project in Pakistan for the last few years.

$${}^{t}D = \{D\ell t\}, \quad \ell \in L, \quad t \in [t_0, t_s] (6)$$

Where, $D\ell t$ is the work package executed from the beginning of study period t_0 to present time t_s.

2. Fragmenting obtained set of work packages (D) into groups according to their attributes of work on the basis of natural and climatic zones:

$$D = \{tD_i,.., tD_j,.., tD_k,, t\,D_n\}, \qquad n \in N(7)$$

Where, N-Set of climatic zones in which work package was performed.

3. We shall break each of subsets of work package (${}^{t}Dj$) into preliminary classes. A condition to fall work package in one or other class depends on the actual potential of work in an interval of a respective grouping. Actual potential of work is defined as the volume of excavation works executed in study period:

$$q\ {}^{t}D_1 \in Q_t \quad \rightarrow \ {}^{t}D_1 \in \ {}^{t}D_i \quad (8)$$

$${}^{t}D_1 = \{\ {}^{t}D_{i,n}., \ {}^{t}D_{j,n}., \ {}^{t}D_{k,n},. \ {}^{t}D_{m,n}\}, n \in N, m \in M \ (9)$$

Where, M-set of types of work package

4. Using results of Eq. 2 & 3, for each study year by month we shall generate a matrix of type (m*n) classification grouping of work package on specific climatic zone (column) and to with specific potential of work(row):

$${}^{t}D_1 = \begin{vmatrix} {}^{t}D_i, 1 \ldots, & {}^{t}D_j, 1 \ldots. & {}^{t}D_k, 1 \ldots., & {}^{t}D_n, 1 \\ {}^{t}D_i, 2 \ldots., & {}^{t}D_j, 2 \ldots., & {}^{t}D_k, 2 \ldots., & {}^{t}D_n, 2 \\ {}^{t}D_i, M \ldots, & {}^{t}D_j, M \ldots, & {}^{t}D_k, M \ldots, & {}^{t}D \ \ M, N \end{vmatrix} (10)$$

Where, ${}^{t}D_{i,1}$- Work package of i-th type, worked in 1st climatic zone in t-th month.

5. For every type of work package, a performance characteristic is constructed to fulfill works with specific conditions in one month period working on 1-st Phase.

$$\mathrm{q},1,\ell=\{1,\mathrm{q},\mathrm{D}_{i,1,\ell},\ldots\ldots,\mathrm{t},\mathrm{q},\mathrm{D}_{i,1,\ell}\},t\in \mathrm{T1}(11)$$

Where T1 - duration (in months) for performing work package of ith class, in 1^{st}climatic zone on construction 1^{st} phase.

6. Maximum (C point) and minimum potential (B point) of work in the system of each type of work packages in different climatic zone in t-th month can be given as;

$$\mathrm{B}=\{\ {}^{t}\mathrm{q}\ \ ,\ {}^{1}\mathrm{D}_{i,1,\ell}|\ \ \ {}^{t}\mathrm{q}\ \ ,\ {}^{1}\mathrm{D}_{i,1,\ell}\ \ \geq q\forall\ i,1\},\quad t\in\ \mathrm{T}\ \ (12)$$

$$\mathrm{C}=\ \{\Delta\ {}^{t}\mathrm{q}_{\mathrm{D}_{i,1,\ell}}|\ \Delta\ {}^{t}\mathrm{q}_{\mathrm{D}_{i,1,\ell}},\leq\alpha_{i,1}\mathrm{Q}_{\mathrm{D}_{i,1,\ell}}\},t\in\mathrm{T}(13)$$

For each climatic zone and potential type of work packages, it is possible to get values of parameters as a result of research of dynamic functioning of technological streams in construction. Between maximum and minimum potential level (M_{max} and M_{min})lies set of intermediate potential levels. Thus, individual work package, examined in system, during each fixed moment of time t can be on one of potential levels. Transfer of one level of potential for a specific work package to another is carried out by changing the structure, resulting from depending potential. For allocating potential level to a specific type of work package in specific zone the following three options are possible.

a) On the basis of developed model;
b) On the basis of formal statistical data;
c) Combination of two.

$${}^{t}M_{\mathrm{i}}\ \ =\frac{k_i}{K}\ {}^{t}M_{\max j}+\frac{(K-k_i)}{K}\ {}^{t}M_{\min j}\quad(14)$$

Where ${}^{t}M_{i}$- a potential level in system w.r.t corresponding conditions of i-th type of work package in t-th month;

k_i -Number of i-th potential type of work packages;
K-Total number of potential types of work package;
${}^{t}M_{max,\ j}$- the maximal value of a work potential level in the system w.r.t. corresponding conditions in t-th month, in j-th climatic zone;
${}^{t}M_{min,j}$- the minimal value of a work potential level in system w.r.t. corresponding conditions in t-th month, in j-th climatic zone.

The calculation of potential of work on statistic data, it can be done by average arithmetic, average regression and average progression values of potential level of work package. An average arithmetic potential level of work package is given as; (Formula 15)

$${}^{t}M_{\mathrm{j}}\ \ =\frac{\sum_{s}\cdot\sum_{1}\ q\mathrm{D}_{i,1,\ell}}{\sum_{1}\ \mathrm{D}_{i,1,\ell}}\cdot\mathrm{D}_{\ell}\forall S\qquad(15)$$

where${}^{t}q_{Di,1,\ell}$ - actual volume of works executed by S-th zone i-th type of work package in j-th climatic zone on construction of 1-st gas main in t-th month;
t D_1 – Volume of work package done on 1-st gas pipeline in t-th month.
Finding the work potential in specific climatic zone and in specific time (month of the year) we can put obtained data in real plan of work shown in figure 2. As shown in figure 2 the work is scheduled in a way to minimize the float time in the project and maximum utilization of resources. The Project is broken in Phases and then further to sections and Work package are defined as D_1, D_2, D_3 and so on of section S_1, S_2, $S_3$and so far of the pipeline.

5. RESULTS AND CONCLUSION

1. For pipeline projects, performance of work of set of activities or work package may not be effectively be calculated on the basis of standard planning data.
2. Linear part of pipeline passes through different regions, climatic zones and in different time zones, therefore, ordinary project management techniques cannot be used to execute, monitor and control the pipelines projects. For effective project management of such structure, parameters such as type of work, geographic and climatic conditions of the zones through which pipeline is passing.
3. Resources like time, manpower and machinery can be optimally utilized by making construction plan optimized i.e. in a way that repeating activities of each zone are joined with Finish to Start logical relationship to the other zone or section so that resources are moved to other section without wastage of time and making process more efficient and cost effective.
4. Finding the work potential in specific climatic zone and in specific time (month of the year) we can optimize plan / schedule of gas pipeline projects as shown in Figure 4. According to it, work is scheduled in a way to minimize the float time in the project and maximum utilization of resources. The project is fragmented in phases and then further to sections and work package as defined as D_1, D_2, D_3 and so on of section S_1, S_2, S_3 and so far of the pipeline in accordance to equation 14 & 15 mentioned above.
5. The calculation of potential of work to be done on statistic data, it can be done by average arithmetic, average regression and average progression values of potential level of work package. An average arithmetic potential level of work package is given as in equation 15.
6. The output and efficiency of construction system developed in accordance to figure 1 shows that internal and external organizational factors, termed as internal or external risk influence the system to hinder the performance of project. Therefore risk management should be the integral part of project management system.

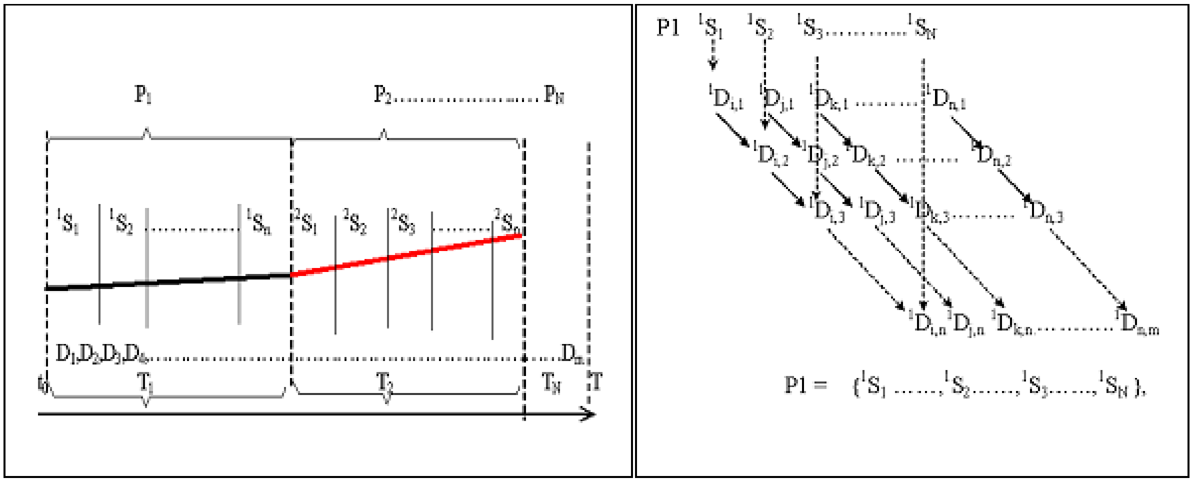

Figure 2. Work flow diagram depending upon the developed model of 1st gas pipeline having sections S1, S2.

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REFERENC

[1] Mubin, S., U. A. Goryainov, Construction and Operation of Pipeline Projects in Pakistan-Associated Risk and their Solution. *Natural Gas*, ***50*** **(4):** 55-60(2007)

[2] Beall, J. Assessing and responding to urban poverty: lessons from Pakistan. IDS Bulletin, **28**(2): 58-67(1997).

[3] Overview of the Economy, Economic Survey of Pakistan (2006) available on http://www.embassyofpakistanusa.org/forms/overview_1.pdf accessed on 10-10-2010

[4] Economic Survey of Pakistan, http://www.finance.gov.pk/survey/chapters_13/14-Energy.pdf accessed on 8-8-2014 pp: 187-197 (2013)

[5] Sui Northern Gas Pipeline Limited, Pakistan, http//www.sngpl.com.pk accessed on 15-10-2013.

[6] Toufiq, A. S. India and Pakistan: pipe dream or pipeline of peace? *Georgetown Journal*,**5**(1): 35-42, (2004)

[7] Robert, K.W. *Effective Project Management*, John Willey and Son. pp: 230-236, (1995)

[8] Молдованов О.И., В.И. Орехов и др. Производственный контроль качества в трубопроводном строительстве Москва Недра pp: 339-341, (1986)