

Rural Infrastructure Planning with emphasis on road network connectivity by Coplanar Concurrent Theory

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Introduction:

Rural roads are an important sector in rural development, which deals in all aspects of development including agriculture, health, education, forestry, fisheries, small-scale industries, trade, commerce etc. that depends on good communication. Rural transportation network will give shape to the living environment of villagers; rather roads of rural transportation are the connectivity elements in our society. Appropriate combination of various links both technically and economically can generate rural traffic infrastructure, which should be prepared for the measure of land development. Rural road connectivity is not only the key component of Rural Development in India, it is also recognized as an effective poverty reduction programme. An improved accessibility to all quarters of a village is an indispensable prerequisite for the provision of adequate living conditions in rural areas. The interdependency in change of land use and transportation is not promoted in rural areas and this keeps the economic system inactive in these areas. The absence of roads in rural areas leads to stagnation of socio-economic conditions of the villagers.

The network planning should promote the objectives like accessibility and connectivity to most of the places in the region. There is a wide difference in the development of land use system in rural and urban areas. The settlements in urban sprawl will place, irrespective of local road network, whereas in rural areas, the resources are to be connected to the marketing centers for promoting transitional changes in socio economic status of people. A proper skeleton of road network will create a promotional impact of land use activity.

The present scenario in India warrants a serious thought on planning rural road network in a scientific way. The existing research work in the area of planning is limited to modification and upgradation of the existing planning approaches already developed. Attempts are being made to incorporate the socio-economic parameters, local transport system and transportation cost aspects. The existing regional rural road planning practices are mainly based on adhoc criteria and lack of scientific research, which are not giving any insight on pattern of connectivity. The current planning practice in India considers the connectivity based on the population of the villages and the small sized villages tend to get neglected in this method. The planning of rural road is not made in a comprehensive and co-ordinated manner.

Another imbalance is the rural urban dichotomy. In developing countries, though the percentage of population living in rural areas is high, still 50 – 75% of the villages are yet to be connected. At this juncture, there is an urgent need to develop a scientific methodology for the assessment of rural travel demand, which can promote a road

network of hierarchical importance and wider range of connectivity basically from user, system owner and land use planning point of view.

Computers have been applied in planning almost since their inception, but only recently with the development of graphics, distributed processing, and network communications has software emerged which can now be used routinely and effectively. At the basis of these developments are Geographic Information Systems (GIS) but gradually, these are being adapted to the kind of decision and management functions that lie at the heart of the planning process. Using GIS to support a wide range of planning and management operations will make an enormous impact towards guiding the development and growth of rural areas. Rather than aiming at optimal solutions, pragmatic approaches must rely on the usage of heuristic problems capable of supporting the dynamic requirements of the domain. Hence the spatial entity when associated with the non-spatial attributes will be useful to achieve most rational infrastructure strategy. This is a key factor for applying GIS technology as a tool in supporting road network planning.

Rural Transportation scenario in India:

In the hierarchy of road system in India, rural roads include Other district roads (ODR) and Village roads (VR). There are about six lakh villages spread over 3.28 million square kilometers area. There were road development programmes like Minimum Needs Programme (MNP) and Basic Minimum Services programme (BMS) which envisaged provisions of connectivity to all villages and habitations by the end of 2002 AD. According to the recent study by Planning Commission only three-fifths of the nearly 6 lakh villages are known to be connected by all weather roads. In 2000, a Centrally Sponsored Scheme called the Pradhan Mantri Gram Sadak Yojana was announced with the objective of connecting every village that has population more than 500 persons by the year 2007.

Elements of successful rural road network:

- Identification of demand potential
- Wider coverage and Demand dominated connectivity
- Potential service centres
- Uniform coverage of village nodes
- Hierarchical linkage pattern
- Minimisation of gap between direct and indirect cost

Objectives:

The existing practices in rural road developments have to be tackled with scientific inputs for effective reorientation of network elements and also to subdue the inconsistent growth of land use activity in regional areas. In order to achieve a desired network to road user and system owner and to overcome the limitations in the current practices, following are considered as objectives of this study.

1. To develop a simpler method of demand potential of nodes, which can serve as a proxy to the actual travel behavior of users.

2. To develop a methodology which can identify uniform road connectivity for the compatible development of the area with GIS as a supporting tool.
3. Coordination of existing road network and the proposed road network and develop the missing links.
4. To assess and generate the road network configuration on the basis of demographic and socio-economic characteristics thus assessing the socio-economic impacts on the roads
5. To develop a user, system owner based and cross composition based network for wider coverage of the given area

Methodological framework:

Transportation network is a spatially designed stationary system to act as a framework for the non stationary activities. The road network has been developed in a 4 level segregated pattern. Each level is incorporated in the layer form in the vector based GIS software. The layer system is developed using the following modules.

Module 1: Mapping of the existing boundaries derived from the secondary sources which include the district boundaries and the village boundaries.

Module 2: Development of the existing road network from the satellite data with the resolution of 30 m and toposheets of 1:25000 scale.

Module 3: Mapping of road network obtained from coplanar concurrent theory

Module 4: Coordination of all the above three layers to obtain the final road network configuration and identify the missing links.

Methodological concept used in the study:

An attempt has been made to obtain the orientation of the corridor by applying the concept of “Resultant of coplanar concurrent force system” and later the road network configuration is developed using “Gravitational pull theory” and “Principle of moment” concepts. A hierarchical and optimal road network is developed scientifically based on the basic principles of physics assuming the mandal as a rigid body. The relative force of attraction in the gravitational pull theory between two bodies is used to analyse the demand potential of a particular place. The concept is justified from the fact that the attraction to a particular place is proportional to the impedance (distance) and the activities / facilities taking place (which is represented by the force / score of the particular place. This concept contributes to the development of broad based planning framework having diverse perspectives. Incorporating gravitational pull theory and principle of moment concept will involve village connectivity and will result in overall progress providing connectivity to remotest villages of the area.

Assumptions in formulating methodology :

The following assumption are made in conducting the analysis:

1. Each Mandal is assumed to be acting like a Rigid body. (defined as “a definite amount of matter, the parts of which are fixed in position relative to one another”)
2. The Mandal Head Quarters of each mandal is taken as the Origin.
3. The line of action of forces of each and every village in a particular mandal is assumed to be originated from the Mandal Head Quarters.
4. The force of attraction between a Village and Mandal Head Quarters can be obtained by : $F_1 = S_v * S_{mh} / d^2$ v-mh

Where F_1 = Force of attraction between village and Mandal Head Quarters of a particular mandal.

S_v = Score of village

S_{mh} = Score of Mandal Head Quarters

The scores of village and mandal Head quarters are obtained by taking the demographic, Socio-economic factors and infrastructural facilities of that particular location into consideration.

5. The resultant lead obtained is assumed to serve as a corridor to serve the villages in a particular mandal.
6. The moment of each village can be obtained by
 $M_v = S_v * d$
 Where M_v = moment of the village about the Mandal HQ
 S_v = score of each village
 d = distance of separation between village and Mandal HQ
7. The moment is assumed to represent the relative importance of a village.
8. The angle of deviation is measured counter-clockwise from the positive X-axis.
9. Appropriate Scores are assumed for the Villages and Mandal Head Quarters whose data is missing.

Algorithmic steps for identification of road network from coplanar concurrent theory:

In general a rural area is composed of number of mandals which in turn have various villages. The methodology is briefly presented in the following algorithmic steps. The census information is used for advancing a technique for rural road network planning in a multi dimensional framework

Step 1: The various facilities available in the village are obtained from the census records and the data processing is done by assigning a set of points (Source: World bank guidelines) to the various facilities available in a village by a unique scoring pattern. Finally, a road need assessment rating shown in table 1 will be used to rank the qualifying roads to establish priority of intervention. The cumulative score of all the facilities is considered as the force of the village. These scores which are unique in nature represent the force of that particular village. In other words, it represents the relative inherent strength or potential of that village among a set of other villages, in developing its accessibility to the mandal Head Quarters. Thus the priority of that village amongst the cluster of villages is determined.

Table 1: ROAD NEED ASSESSMENT RATING:

Source: Option for Planning, Managing and Financing Rural Transport Infrastructure- World Bank Technical Paper No : 411(Author: Christina Malmberg Calvo)

SECTOR	FACILITY	POINT
Educational	P: Primary or Elementary School (up to Class IV)	05
	M: Middle School or Junior Secondary (Class V to VIII)	10
	H: Matriculation or Secondary School (Class IX and X)	15
	JC: Higher Secondary / PUC	20
	C: College (graduate level and above)	25
	I: Industrial School	30
	Tr: Training School	50
	Ac: Adult literacy class /Center	50
	O: Others	20
	When Educational facility is available at a distance of :	
	- less than 5 kms	15
- 5 to 10 kms	10	
- 10+ kms	05	
Communication	BS: Bus Stop	25
	RS: Railway Station	50
	NW: Navigable Waterway	20
	When Communications facility is available at a distance of :	
	- less than 5kms	20
- 5-10kms	15	
- 10+kms	10	
Post & Telegraph	PO: Post office	25
	TO: Telegraph office	25
	PTO: Post & Telegraph office	50
	Phone: Telephone connection	75
	When Facility is available at a distance of:	
	- less than 5kms	20
	- 5 to 10kms	15
	10+kms	10
	TW:Tube Well	30
	HP:Hand Pump	30
R: River	25	
F: Fountain	20	
C:Canal	20	

	L:Lake S:Spring N: Nallah O: Others When drinking water facility is available at distance of, - less than 5km - 5 to 10kms 10+kms	20 20 10 05 15 10 05
Approach to the Village	PR: Pucca road KR: Kachha road FP: Foot path NR: Navigable river NC: Navigable canal NW: Navigable Waterway	50 40 25 15 15 15
Power Supply	ED: Electricity for Domestic purpose only EAG: Electricity for agriculture purpose only EO:Electricity for other purpose like, industrial commercial etc., EA: Electricity for all purpose listed above	50 50 50 150
Land Use	Culturable Waste: More culturable waste, Less points Less culturable waste, More points Area not available for Cultivation: More area, Less Points Less area, More Points	
Households and Population	More people, more households—more points Less people, less number of households—less points	

Step 2: Mandal head quarters is identified and it is taken as the origin for drawing an arbitrary axis.

Step 3: The angle of deviation of every village with respect to Mandal head quarters is measured.

Step 4: Each force is then resolved into components that coincide with chosen axis.

Step 5: The components of each force with respect to these axes can be added algebraically and the resulting additions will be the components of the overall resultant vector (Rx & Ry)

Thus

$$R = \sqrt{(\sum X)^2 + (\sum Y)^2}$$

$$\tan \theta_x = \sum Y / \sum X$$

θ_x gives the direction of the resultant. Therefore, the orientation of the corridor from the Mandal headquarters is obtained.

Step 6: Calculate the force of attraction between Mandal head quarters and each node by Gravitational formula. The data used is scores (Force) of villages and distance of separation. The village with highest force of attraction is identified and network is

proposed in that direction. A line is drawn connecting this village centroid with Mandal Head Quarters. Thus, another lead from Mandal Head Quarters is obtained

The force of attraction between the village and mandal headquarters is
 $F1 = Sv * Smh / d^2_{v-mh}$

Where Sv = Score of village

Smh = Score of Mandal Head Quarters

d_{v-mh} = distance of separation of the village from Mandal Head Quarters.

Step 7: Calculate the moment of each village with respect to Mandal Head quarters. The higher the moment of the village, more importance the village gets in connection.

Thus, $M = Sv * d$

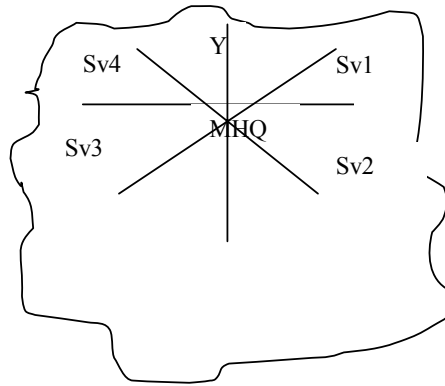
Where Sv = Score of the village

d_{v-mh} = distance of separation of the village from the Mandal Head Quarters

The village with highest moment is identified and this village is connected with the Mandal Head Quarters.

Step 8: Develop the road network with respect to the derived resultants. From the above three resultants, each user node is connected to the respective resultants at a minimum path on the consideration road pattern. This approach controls the

hierarchical maintenance of the road.



Representation of forces in a mandal

MHQ =Mandal Head Quarters

Sv1,Sv2,Sv3 etc =Scores of Village 1, Village 2, Village 3etc

Application of methodology:

This analysis has confirmed the need spatial planning of road network configuration, which can achieve desired results of economic, social interaction and overall development of a region. The study is attempted on the Medak district of Andhra Pradesh, India. This district consists of 45 mandals in which there are 1265 villages. In this district, most of the villages are inhabited, accounting to 92.27% of the total population of the district. In most of the villages, the population range is from 500 to 999.

The methodology is applied in the following steps.

Module 1: Development of Layer1:

Existing boundaries derived from the secondary sources are shown in fig1.

Module 2: Development of Layer2

Existing network is developed from the satellite data and topo sheets using ERDAS software and is shown in fig 2.

Module 3: Development of road network from coplanar concurrent theory (Layer3):

Determination of the score of the villages :

The following attributes have been selected for each of village from the town and village directory of the district,

- Total number of households,
- Total population,
- Educational facilities(Primary school, Middle School, Secondary School, Junior College, College Industrial school etc.,)
- Medical facilities (Hospital, Maternity and Child welfare center, health care, Dispensary, T.B.Clinic, Family planning center etc.),
- Drinking water (Tap, well, tank, tubewell, handpump, river, fountain, canal etc.,)
- Post and telegraph (Post Office, telegraph office, telephone connection etc.,)
- Communications (Bus stop, Railway station, waterway etc.,)
- Approach to a village (Pucca road, Kachcha road, Foot path, Navigable river etc.,)
- Power supply (Electricity for domestic purpose only, Electricity for agriculture purpose only, Electricity for other purpose like industrial, commercial etc., Electricity for all purpose listed above)

A sample calculation of the score of a village named “ Telema” in the Angole mandal of Medak district, Andhra Pradesh, India is shown below:

Name of the village: Telema

Number of Households = 343

Population of the village = 1949

Amenities available: Educational : P, AC (5,50)

Medical: Within 5 –10 kms(20)

Drinking water(Potable): W, HP(40,30)

Post and Telegraph : -5(20)

Communicaions: -5 (20)

Approach to village: KR(40)

Power supply: ED, EAG(50,50)

The values in the brackets indicate the points.

Hence the score of the village $S_v = 375$ (Summation of all the above points). Thus the scores were calculated for all the villages and all the mandals. The following table2 shows the scores for one mandal named “Andole”

Table 2: Scores of villages in Andole mandal

ANDOLE		
Code No of the Village	VILLAGE NAME	SCORE
2123	TELELMA	375
2119	SERIMALLAREDDIPALLE	325
2121	KANSANPALLE	355
2109	RAMSANPALLE	385
2117	KICHANAPALLE	365
2113	CHINTAKUNTA	390
2112	ROLLAPAHAD	305
2111	MANASANPALLE	360
2115	POSANIPET	375
2114	ANATHASAGAR	385
2116	DANAMPALLE	355
2118	YERRARAM	315

2120	NEERDIGUNTA	440
2134	BRAHMANPALLE	345
2132	AKSANPALLE	370
2133	TADAMANOOR	350
2136	KODEKAL	355
2135	NADLAPUR	300
2137	DAKOOR	555
2138	MASANPALLE	355
2141	SAIBANPET	360
2140	ALMAIPET	800
2143	SANGUPET	365
2145	POTHAREDDIPALLE	365
2147	KONDAREDDIPALLE	355
2139	JOGIPET	-

The algorithmic steps mentioned above have been applied to all the 45 mandals and the output obtained is shown for one mandal in table 3.

The connectivity for the Andole mandal is shown in figure 3

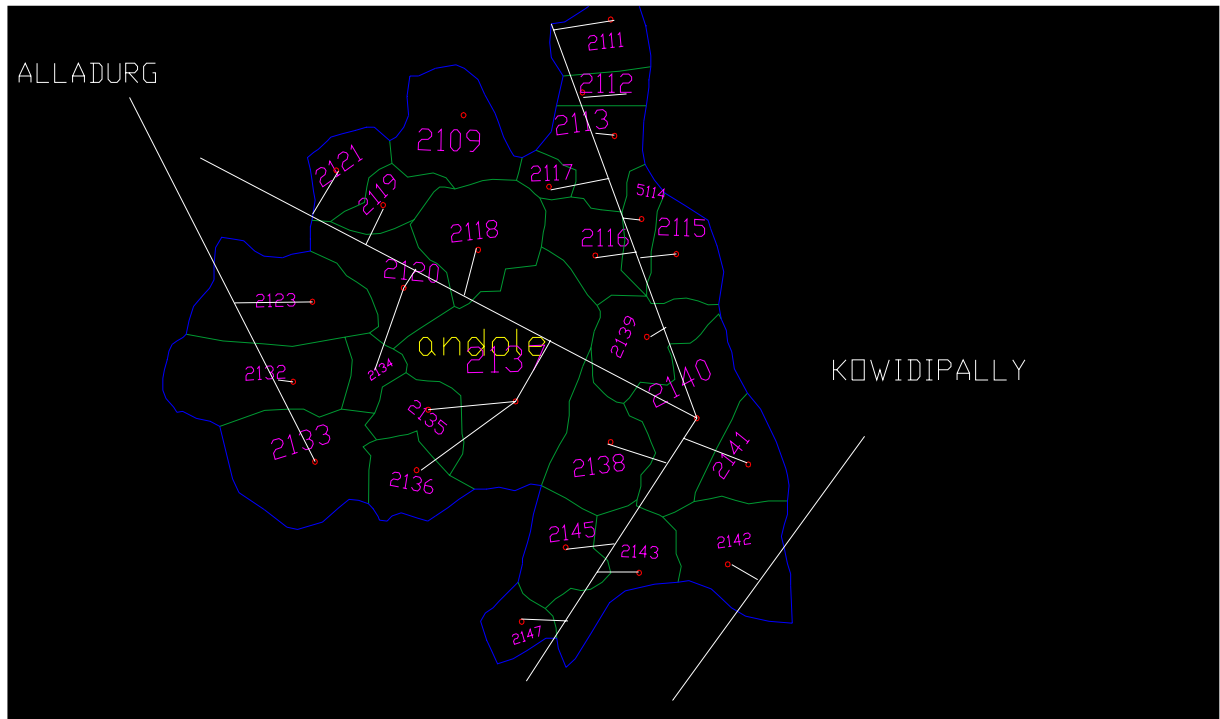


Fig 3: Connectivity pattern for Andole mandal

The whole connectivity for the entire district is kept in a layer and is shown in fig 4.

Evaluation:

The analysis is carried out on 45 mandals of Medak district covering nearly 1265 villages. The model developed with the concept of the Resultant Coplanar Concurrent Force System, is able to identify the direction of orientation of the corridor from Mandal head quarters having wider coverage. Incorporation of Gravitational pull

theory and principle of Moment gives the travel desires which is a straight line connecting the Mandal head quarters with the village having a highest value

Comparison of road length existing & suggested:

The Total road length of the proposed road network configuration = 3358.28 km

Total geographical area of all villages in each mandal of district per 100 km² = 96.67km²

Total Distance / Total Geographical area = 3358.28 / 96.67 = 34.74 kms

According to Indian Roads Congress recommendations it was decided to provide 32 km to 82 km of surface road length for every 100 sq.km of land. Result obtained (i.e., 34.74 km) is in between the stipulated range which is economical.

Module 4: Development of final Road network configuration:

Coordination of proposed road network and existing road network:

This task has been achieved in Arc Info software and the result is shown in Fig 5.

This has been useful for identifying the missing links .

Conclusions:

The integration of information derived from RS technologies with other data sets, both spatial and non-spatial formats, provides tremendous potential for characterization and analysis of earth surface resources. Such derived information needs to be understood carefully in relation to the socio-economic situation for planning and development for sustainable growth employing GIS tool.

This analysis has confirmed the need for spatial planning of road network configuration, which can achieve the desired results of economic, social interaction and overall development of a region. This study involves a methodology for rank ordering the various settlements, so that, priorities for linking the settlements can be worked out. The road network configuration is developed based on weightages (scores) that have been given to different forms of facilities for each of the villages from the town and village directory of this district. The direction of orientation of the resultant corridor from each mandal head quarters of each mandal is developed from the concept of “Coplanar Concurrent Force System”. This concept contributes to the development of broad based planning framework having diverse perspectives. Incorporating Gravitational theory and Principle of moment will improve village connectivity and may result in overall progress by providing connectivity to remotest villages of the area. The main contribution of this study is stressed on developing weightages to various settlements, incorporation of concept of Resultant of Coplanar Concurrent Force System

GIS is found to be a powerful tool for data integration and modelling for all levels of planning. In India, GIS is not being used by planners and decision makers as intensively as it should have been used. It is hoped that with the increased awareness and reduced cost of hardware and software in future, GIS technology will become a part of our life for planning even day to day activities.

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Map India 2003

Transportation

Code No	Score Sv	Mandal Score S _{mh}	Deviation	Distance in cms	Distance in kms (d) Cms*2.5	M = Sv * d	F = Sv*S _{mh} / dv-nh**2	Angle in radians	Fx = F cos(θ)	Fy= Fsin(θ)	Scale ratio
2123	375	800	161	4.9	12.25	4593.75	1999.16701	2.8099801	-354.5694658	122.0880579	0.5
2119	325	800	140	4.3	10.75	3493.75	2249.86479	2.4434609	-248.964444	208.9059731	0.4
2121	355	800	142	4.9	12.25	4348.75	1892.54477	2.47839754	-279.7438175	218.5598237	0.5
2109	385	800	127	4	10	3850	3080	2.21656815	-231.6987839	307.4746714	0.5
2117	365	800	114	3.3	8.25	3011.25	4290.17447	1.98967535	-148.4588747	333.444092	0.5
2113	390	800	104	3.4	8.5	3315	4318.3391	1.81514242	-94.34953928	378.4153332	0.5
2112	305	800	95	3.9	9.75	2973.75	2566.73241	1.65806279	-26.58250154	303.8393829	0.4
2111	360	800	96	4.5	11.25	4050	2275.55556	1.67551608	-37.63024678	358.0278823	0.5
2115	375	800	92	2.1	5.25	1968.75	10884.3537	1.60570291	-13.08731126	374.7715601	0.5
2114	385	800	100	2.2	5.5	2117.5	10181.8182	1.74532925	-66.8545484	379.1509849	0.5
2116	355	800	120	2.9	7.25	2573.75	5403.09156	2.0943951	-177.5	307.4390183	0.5
2118	315	800	140	3.4	8.5	2677.5	3487.88927	2.44346095	-241.3039996	202.4780971	0.4
2120	440	800	146	3.7	9.25	4070	4113.95179	2.54818071	-364.7765319	246.0448775	0.6
2134	345	800	170	3.7	9.25	3191.25	3225.7122	2.96705973	-339.7586748	59.9086213	0.5
2132	370	800	172	4.4	11	4070	2446.28099	3.00196631	-366.3991854	51.49404736	0.5
2133	350	800	178	4.3	10.75	3762.5	2422.93131	3.10668607	-349.7867895	12.21482385	0.5
2136	355	800	184	3.1	7.75	2751.25	4728.40791	3.21140582	-354.1352378	-24.76354818	0.5
2135	300	800	168	2.8	7	2100	4897.95918	2.93215314	-293.4442802	62.37350725	0.4
2137	555	800	153	2.1	5.25	2913.75	16108.8435	2.67035376	-494.5086209	251.9647274	0.7
2139	0	800	107	1.5	3.75	0	0	1.8675023	0	0	0
2138	355	800	168	1	2.5	887.5	45440	2.93215314	-347.2423983	73.80865024	0.5
2140	800	800			2.5	2000	102400	0	800	0	1.1
2141	360	800	337	0.8	2	720	72000	5.88175958	331.3817472	-840.6632063	0.5
2142	380	800	296	1.4	3.5	1330	24816.3265	5.16617459	166.5810358	-341.5417376	0.5
2143	365	800	247	1.1	2.75	1003.75	38611.5702	4.31096325	-142.6168619	-335.9842715	0.5
2145	365	800	226	1.8	4.5	1642.5	14419.7531	3.94444411	-253.5503052	-262.5590271	0.5

Map India 2003

Transportation

2147	355	800	226	2.6	6.5	2307.5	6721.89349	3.94444411	-246.6037215	-255.3656291	0.5
								Total =	-4175.603357	2891.526712	

Table 3: Output for the Andole mandal

Resultant = 5079.034369

Fy/Fx = 0.692481173