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Driver perception of superimposed horizontal and vertical road curves for bi-directional roads

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Abstract. With additional dimensional elements, the road appearance gets complicated and hence there is a possibility of erroneous reactions from drivers, which can cause a safety hazard. This paper assesses the perception abilities of the drivers for different roads with superimposition of horizontal and vertical curves. The questionnaire of the survey has been designed as a set of slides, each containing two 3-D images of simulated roads having different values of vertical and horizontal curve parameters at various staggering levels arranged successively. The renderings during the design are made with a camera set in congruence with the eye level of the driver on the road. Sixty drivers have been interviewed with this questionnaire, and their ability to distinguish between the curves is recorded as a categorical variable (Yes or No). The responses are modeled using logistic regression wherein the curve parameters and driver demographics are explanatory variables. From the model, it has been observed that the ability to differentiate between the curves decreases with higher radius of the horizontal curve, and higher staggering of the superimposed horizontal and vertical curves. Furthermore, drivers can perceive differences in vertical geometry better than in horizontal geometry. The drivers can distinguish two successive similar curves if the geometric parameter difference is higher, as evident from the model. With the lack of field models, results from this experimental study can be a cue for transportation planners for designing overlapping geometry.

Keywords: Driver Perception, Horizontal Curves, Vertical Curves, Superimposed Horizontal and Vertical Curves.

1 Introduction

The geometric design is a primary factor that determines the overall safety and effectiveness of road designs. Traditional design standards are established considering different parameters in relative isolation. However, in road systems consisting of more complex designs with multiple geometric parameters overlapping and interacting with each other, it becomes imperative to perform empirical studies that evaluate their safety.

Horizontal curves are geometric design parameters that are incorporated into road designs as they provide a gradual change in direction of the road (Khan, 2012). Whereas vertical curves provide a transition between two sloped roadways, allowing vehicles to negotiate the elevation rate change at a gradual rate rather than a sharp cut. (Levinson, 2021). Current manuals like IRC:38-1988 ‘Guidelines for Design of Horizontal Curves for Highways and Design Tables’ and IRC SP 23 (1993) ‘Vertical Curves for Highways’ have various guidelines for designing horizontal and vertical road curves respectively, but have little information for road designs which have both these parameters overlapping at once.

In such cases, driver perception of the curve becomes a critical determining factor. Several studies (Hassan & Easa, 2003), (Hanno, 2004), etc. have proved that the ability of drivers to perceive the characteristics of the road and hence opt for appropriate speed and direction controls of the vehicle is limited. Erroneous perception can lead to compromised safety. For example, if a driver cannot perceive the difference while driving on various roads, we cannot safely assume that he would be able to adopt the appropriate driving operations like speed. Hence, implementing perception-based geometric designs is vital to ensure design consistency and efficacy.

The objective of this study is to examine the accuracy of drivers of distinct age groups and driving experiences to differentiate between computer-generated renderings of roads having varied and overlapping horizontal and vertical curve parameters. Further, the paper tries to establish a relationship between perception accuracy and the various parameters horizontal and vertical curve radius, angle of deflection of vertical road, driver demographics, etc.

2 Literature Review

2.1 Literature related to Driver Perception

Junjie et al. (2021) studied the role of driver’s perception errors for vehicle motion state information in affecting traffic flow oscillations. A real vehicle test and an extended full velocity difference (EFVD) model were used to investigate the effects of the driver’s perception errors of the preceding vehicle’s velocity and headway changes on a road without lane-changing. Results from numerical experiments illustrated that the increase of the interval of the confidence levels is not conducive to smooth traffic flow in those cases. Yang et al. (2018) combined a field operational test and numerical simulations of a typical rear-end crash model to estimate the probability of crash occurrence. Time-to-collision (TTC) and driver braking response to impending collision risk were used in an instrumented vehicle to evaluate a decrease in crash probability. Peter et al. (2018) explored the detrimental effect of vertical eye-movement carryover from one driving task to another for hazard identification accuracy. It was observed that scanning accuracy was higher for experienced drivers and horizontal scanning movement. Johan et al. (2020) explored which curve cues and other variables influence drivers’ speed choice in curves through specifically designed surveys. Geometric road characteristics such as curve radius and deflection angle were identified by the respondents as influencing variables but only shown to affect speed selection when these are visible to the driver and not obscured by trees or other elements. Hassan and Easa (2003) studied driver perception of computer-animated 3D representations of horizontal roads with and without overlapping vertical curves and found that driver behavior on horizontal curves depended on the overlapping vertical curve. Similarly, Hanno (2004) analyzed driver perception with respect to 3D effect of combined road alignment and found that many parameters like horizontal curve radius, the algebraic difference in vertical gradients, the percentage of overlap between the vertical and horizontal curves, etc., significantly affected driver perception in various ways.

2.2 Literature related to Horizontal and vertical curves

Mohsen et al. (2020) evaluated the effect of overlapping longitudinal slope and vertical curves on the horizontal curve radius by exerting different forces on a vehicle and modeling the direction of their effect. The results demonstrated that the equations for the overlap of a horizontal curve with a crest vertical curve indicate a need for increasing the horizontal curve radius in some cases. Sil et al. (2018) developed a speed prediction model for horizontal curves under mixed traffic conditions in a four-lane divided highway. It was observed that some drivers use the full width of pavement to traverse a horizontal curve in a free-flowing condition. Hence, the speeds of these vehicles were relatively higher and did not demonstrate significant speed reduction while entering from a tangent section. Wang et al. (2018) studied the speed change behavior of various combined curves. An analysis of the marginal effects of different parameters of combined curves on speed change showed that the type of combined curve affected the speed change behavior of the driver. Nama et al. (2016) evaluated the performance characteristics of vehicles for hilly roads using indirect measures such as stability of the vehicle, velocity, and stress on the driver on various hilly road sites. The observations suggested that operating speeds are higher than design speeds. Cheng (2020) predicted the probability of roadside accidents for curved sections on highways. The results showed that after vehicle speed, horizontal curve radius was the most significant risk factor.

2.3 Literature related to curves in mixed traffic conditions

Munigety et al. (2016) studied and formed a comprehensive review of studies that consider modeling integrated driving phenomena like tailgating, multiple-leader following, swerving, and filtering in mixed traffic conditions of developing countries. Neena et al. (2021) quantified the influence of geometric characteristics of the preceding curve on crashes and developed models for the evaluation of the safety performance of multiple horizontal curves on two-lane non-urban roads. Sil et al. (2020) quantified the perceived speed behavior at the starting and center of horizontal curves on a National Highway in India and proposed operating speed prediction models for them. Choudhari et al. (2019) investigated the effect of Horizontal Curves on vehicle speed reduction and road safety on two lanes on an Indian Highway using a fixed-base driving simulator to obtain the speed profile of the drivers in various geometric configurations. The maximum speed reduction (MSR) values for a fair level of safety were calculated which can be used to design horizontal curves. Shallam et al. (2016) carried out Operating Speed Models on horizontal curves for two-lane highways to evaluate the 85th percentile operating speed and predict the speed that can match the acceptable design speed. This was used to develop curve-speed prediction equations using data collected at horizontal curves of the highway.

From the above-presented studies, it can be concluded that several studies have shown the importance of driver perception in the safety consideration of a road design. Studies conducted on horizontal and vertical curves in roads have shown that such roads are relatively more prone to accidents and hazard risks and hence need to be critically evaluated with respect to their safety and efficacy, especially in the context of Indian drivers who drive in mixed traffic conditions which is significantly more complex when compared to roads of developed countries.

3 Data Collection Methodology

Studying driver perception of roads with systematically varying geometric parameters in the field can be difficult, considering the fact that even if we find such roads there could be multiple external factors affecting the driver which we cannot control. Hence, we have conducted a limited study, based on the purposive sampling method of the driver population, on their perception of three-dimensional images providing a realistic view of roads as mentioned in Sil et all. 2022. If the drivers are able to perceive the difference between images containing two different curves, they may perceive these curves differently, and react differently to these curves. However, in case they cannot perceive the difference, it emphasizes the inadequacy in perception which has the potential to impede the driver's ability to drive safely. Therefore the study involves providing a series of sets containing two curves, with varied geometric (horizontal and vertical) parameters to be perceived by the driver.

The study is conducted in three stages, i) Developing 3D renderings of road curves with various parameters, ii) data collection from drivers, and iii) modeling the driver responses and analysis (Fig. 1).

Fig. 1. Flowchart of adopted methodology

3.1 Identification of the Parameters

Since the study involves both horizontal and vertical elements, therefore two-lane rural highways with superimposed horizontal and vertical curves are chosen for this study. For this purpose, a variety of parameters that are used in IRC 66-1976 and IRC SP 23-1993 for the design of horizontal and vertical curves respectively, are considered. would describe the geometric design elements of the road are considered. As it is practically impossible to design curves for all possible combinations, specific values are considered for each parameter as follows:

1. Design speed: The target speed at which the drivers are intended to travel on the road. The values considered are (in km/h) 65, 70, 80, 100 and 120.
2. Radius of Horizontal Curve (R): The radius is considered to be around the minimum horizontal radius as suggested by IRC 038, taking superelevation e = 0.07 and friction factor f = 0.15. The values are 155, 180, 230, 360, 520 meters.
3. Angle of Deviation of Vertical Curve (N): It is the difference between the grades of the vertical curve. It is considered in an arithmetic progression starting from 4% with a common difference of 2% up to 10%. The scope of the study is restricted to valley curves.
4. Parameter Q: It is a parameter considered which determines the staggering of the superimposed horizontal and vertical curves. It determines what position of the point (in percentage) in the horizontal and vertical curve that is coinciding in the three-dimensional space. Three Q values are considered, which are- 0 (when the initial points of both the curves coincide), 0.25 (when the first quarter point of the curves coincide), and 0.5 (when the middle points of the curves coincide).

Reaction time t is considered as 2.5 seconds in accordance with IRC:66-1976.

The basic parameters are chosen in such a way that other necessary dependent parameters required to design the curve like the length of the vertical curve (L_v) can be calculated from them.

The horizontal curve is fixed at 45 degrees, and a long tangent follows it. The ratio of the length of the horizontal curve (L_h) to that of the vertical curve is between 0.5 and 2.

3.2 Development of Curve Image Sets

Different software are currently available for rendering 3D models. A 3D design software is needed for this study which can replicate the real world as close as possible with options to incorporate natural lighting, road, roadside geometry, and texture. Some commercially available software for this purpose are Maya [15], 3DS Max [1], AutoCAD [4], etc. For this study, 3DS Max was adopted as it is able to give near-perfect renderings of superimposed horizontal and vertical curves with ease.

Suitable road material is chosen to give a texture to the road. The width of the road is considered

as 7.5 m, with the crown at the center. The shoulder width is kept at 2.5 m. To avoid direction bias, the curves made are right turning only. The terrain is chosen to be flat terrain, with the atmosphere and lighting of the render adjusted to mimic as close to ideal field conditions as possible.

The vertical curve is assumed to be a cubic parabola in accordance with IRC SP 23 (1993). To add smoothness to the road, the horizontal curve is divided into many segments in the X-Y plane as shown in Figure 2. The Z-coordinates of the vertical curve are then calculated and then the alignment is raised accordingly in each division line of the curve. In cases where the length of the vertical curve is greater than the horizontal curve, the segments are extended into the tangent.

A camera is used to set the position and orientation of the view of the rendering to correspond to the driver's perspective on the road. It is set at a height of 1m from the road surface to mimic the average height of the eye level of a driver. The camera is always placed at the beginning of the horizontal curve as shown in Figure 2.

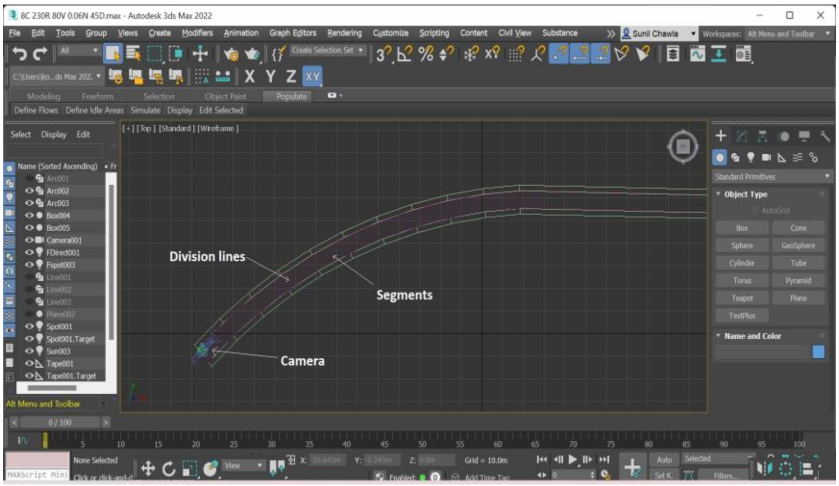


Fig. 2. View of the road in X-Y plane in the 3-D modeling software.

Curve Sets. The pairing of the curves is conducted in a sequential manner, i.e., the base curve (Curve A) remains the same, and the comparison curve (Curve B) changes its parameters in an increasing trend. This is done to analyze different comparisons with a fixed base image. On this basis, two sets consisting of 35 pairs each are formed. (see Appendix Table A1 for details of all the pairings).

3.3 Driver interview process

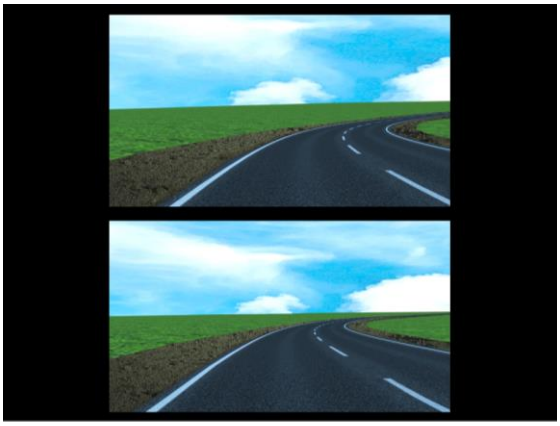
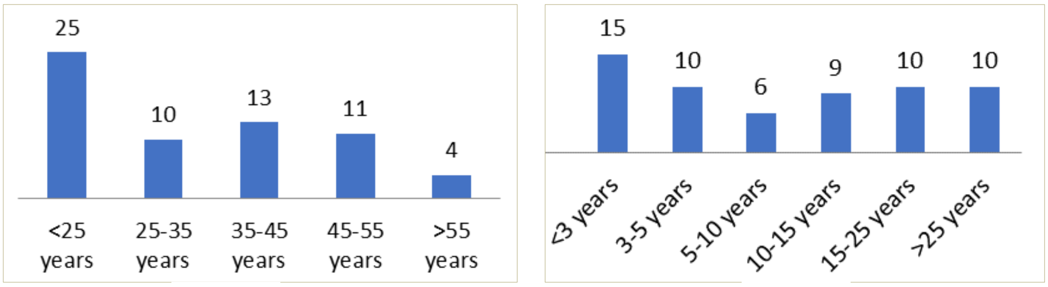


Fig. 3. Sample of curve pairs in survey questionnaire.

Three slideshows are prepared, two of them contain the two sets of curve pairs, and the third one contains a drivers' familiarization set to be used before the actual survey. Each slide consists of one pair of curves (as represented in Fig. 3.) and is followed by a blank slide to record the response of the driver. The slide with the curves is displayed for a fixed interval, which corresponds to the reaction time of drivers as provided in IRC:66-1976, i.e., 2.5 seconds, after which the curves disappear. The drivers' responses after perceiving each pair are expected to be in binary: Yes or No, which indicates whether they were able to differentiate between the two curves or not.

A total of 60 drivers with various age groups, gender, driving experiences, and knowledge of driving in a variety of four-wheeled automobiles are interviewed. 25% of the total drivers were female. The mean age of the drivers is 34.2 years. All drivers had a minimum driving experience of 1 year. Fig. 4. (a) and 4. (b) show the statistical distribution of the drivers.



(a) (b)

Fig. 4. Number of drivers with respect to (a) age (b) driving experience

4 Analysis and results

Overall the data set consists of 2100 data points (60 drivers × 35 responses per driver). Here, the dependent variable is the response of the driver (binary: 0 for no difference or 1 for difference observed), whereas the independent variables are shown in the first column of Table 1.

Table 1. Evaluation using all variables

	Coefficient	Std. Err.	Z	p>|z|
R	-0.0011	<0.001	-2.875	0.004
Change in R	0.0058	0.001	8.761	<0.001
N	0.0307	0.019	1.621	0.105
Change in N	0.3182	0.032	9.873	<0.001
Q	-0.0079	0.003	-2.659	0.008
Change in Q	0.0085	0.004	2.167	0.030
Age	-0.0102	0.006	-1.859	0.063
Gender[1]	0.3775	0.128	2.952	0.003
Experience	-0.0028	0.008	-0.342	0.732
Frequency	0.0141	0.039	0.359	0.720

To model the variation of driver perception (binary) with the independent variables, logistic regression modeling technique is adopted. Firstly the entire dataset is divided randomly into test data (80% dataset) and validation data (20% dataset). The evaluation of the test data using all the variables is given in Table 2. It was found that the variables: angle of deviation of base curve, experience and frequency are not affecting the drivers' decision significantly (their p-statistic value is greater than 0.05)

[1] Gender response is in binary format: 1 for Female and 0 for Male

so they are not considered for further modeling. A new logistic regression model is prepared using the remaining variables. For the driver responses, log-odds (z) expresses the natural algorithm of the ratio between the probability that the driver will not perceive the difference to the probability that he will. Predicted probability (p) of the driver perceiving the difference can be calculated by

$$p = 1 - [\frac{1}{1 + e^{-z}}] \quad (1)$$

where,

$$z = ln\left(\frac{probability\ to\ not\ perceive\ difference}{probability\ to\ perceive\ difference}\right) \quad (2)$$

$$= \beta_0 + \beta_1 R + \beta_2 \Delta R + \beta_3 \Delta N + \beta_4 Q + \beta_5 \Delta Q + \beta_6 A + \beta_7 G$$

β_0 is the constant term, given by the intercept, which indicates overall probability without the influence of any predictor variables, while β_1, β_2, β_3, β_4, β_5, β_6, and β_7, are coefficients of the variables. The model (i.e. values and standard error of β_0, β_1, β_2, β_3, β_4, β_5, β_6, and β_7) is provided in Table 2. R, ΔR, ΔN, Q, ΔQ, A and G are used to represent horizontal radius of base curve, difference in horizontal radius of the curves, difference in angle of deviation of the curves, staggering of base curve, difference in staggering of the curves, age of the driver and gender of the driver respectively.

Table 2. Evaluation using only significant variables.

Variable	Coefficient	Standard Error	z	p>|z|
Intercept	0.6214	0.199	3.115	0.002
R	-0.0016	<0.001	-3.918	<0.001
ΔR	0.0054	0.001	7.918	<0.001
ΔN	0.3133	0.032	9.807	<0.001
Q	-0.0063	0.002	-2.530	0.011
ΔQ	0.0096	0.004	2.674	0.008
A	-0.0189	0.004	-4.657	<0.001
G	0.2959	0.119	2.492	0.013

4.1 Model interpretation

- The vertical angle of deviation of base curve (N), driver experience, and driving frequency are found to have no significant effect on the driver perception of the difference in curves. This result is counter-intuitive to many studies (Alfonsi et all (2018)).
- Drivers are able to distinguish between the curves effectively, if the radius of the base curve (R) is less (as evident from negative β_1 value).

- Greater the difference between the radius of the two images (ΔR), the easier it is for the drivers to perceive the difference between them (as evident from positive β_2 value). This result is in line with the finding of Sil et all (2022).
- The difference in the vertical angle of deviation (ΔN) as well as the staggering value (ΔQ) of the curves has a positive impact on the driver's perception. However, ΔN is seen to have a comparatively greater effect (as evident from positive β_3 and β_5 values respectively).
- The staggering value of the base curve (Q) also had an impact on perception ability. Lesser staggering could be perceived better by the drivers. (as evident from negative β_4 value).
- Female drivers are more likely to perceive the difference than male, while older drivers have lesser perceiving ability in general (as evident from positive β_7 and negative β_6 value respectively).
- Drivers can perceive differences in vertical geometry better than the difference in horizontal geometry.

4.2 Validation

The validation is performed on the validation dataset using confusion matrix. The values of true positive, true negative, false positive and false negative are 109, 94, 66 and 151 respectively, thereby indicating 62% accuracy of logistic regression classifier on the test dataset.

5 Conclusion

The paper presented a methodology to model driver perception, based upon the binary driver response of perceiving the difference between road images consisting of varying horizontal and vertical parameters. It is important to note that although driver response while actual driving is dynamic in nature, the aim of this study was to conduct an initiation into evaluating such perception using limited resources. Logistic regression is used to predict the perception response made by the drivers. Odds to perceive the difference increases with decrease in radius (R); increase in the difference between all geometric parameters of the curves (ΔR, ΔN and ΔQ); and decrease in staggering of the curve (Q). Vertical angle of deviation (N) has little or no impact on perception ability. Age and gender also affect the ability to perceive the difference as noticed from the coefficients, while frequency and experience did not show any noticeable difference in perception. The results are intuitive, with respect to the difference between various parameters of two curves, where the indication is that as the amount of difference increases, the ability to notice it also increases. However, some counter-intuitive findings were also found such as driver experience and frequency not having much impact on such ability of the drivers. This type of study can be adopted as a low cost alternative in the absence of simulators which are mostly inaccessible. It can be regarded as a preliminary study to contribute to the field of perception-based geometric design.

5.1 Application and Future Scope

Erroneous perception can lead to compromised safety and hence implementing perception-based geometric designs is vital to ensure design consistency and efficacy. This information is important while designing the curve combination of horizontal and vertical curves. The outcomes of the study will help the planners to design and construct safer superimposed curves, and assist guiding agencies to formulate thresholds of vertical curves for given horizontal curve geometry, whenever superimposed road geometry is planned, by highlighting the aspects of the geometric design which need to be focused on to ensure the safety of drivers. As concluded from the paper, the engineers may not plan for larger horizontal curves, and use a lesser amount of staggering while designing such combination curves. Building upon this preliminary study, further investigation can be done on such curves using simulators or field studies.

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8 Appendix

Table 3. A1. List of curves and their parameters

Curve Number	Deviation angle(N)	Q	Velocity(v)	Reaction time	f	Lv	Minimum Radius (e=0.07; f=0.15)	Radius considered
1	0.04	0	65	2.5	0.35	66.79	151.255	155
2	0.04	0	70	2.5	0.35	79.24	175.42	180
3	0.04	0	80	2.5	0.35	106.04	229.12	230

4	0.04	0	100	2.5	0.35	167.23	358	360
5	0.04	0	120	2.5	0.35	238.55	515.52	520
6	0.06	0	65	2.5	0.35	108.67	151.255	155
7	0.06	0	70	2.5	0.35	125.89	175.42	180
8	0.06	0	80	2.5	0.35	163.73	229.12	230
9	0.06	0	100	2.5	0.35	252.51	358	360
10	0.06	0	120	2.5	0.35	358.11	515.52	520
11	0.08	0	65	2.5	0.35	144.90	151.255	155
12	0.08	0	70	2.5	0.35	167.86	175.42	180
13	0.08	0	80	2.5	0.35	218.31	229.12	230
14	0.08	0	100	2.5	0.35	336.68	358	360
15	0.08	0	120	2.5	0.35	477.47	515.52	520
16	0.1	0	65	2.5	0.35	181.12	151.255	155
17	0.1	0	70	2.5	0.35	209.82	175.42	180
18	0.1	0	80	2.5	0.35	272.89	229.12	230
19	0.1	0	100	2.5	0.35	420.85	358	360
20	0.1	0	120	2.5	0.35	596.84	515.52	520
21	0.04	0.25	65	2.5	0.35	66.79	151.255	155
22	0.04	0.25	70	2.5	0.35	79.24	175.42	180
23	0.04	0.25	80	2.5	0.35	106.04	229.12	230
24	0.04	0.25	100	2.5	0.35	167.23	358	360
25	0.04	0.25	120	2.5	0.35	238.55	515.52	520
26	0.06	0.25	65	2.5	0.35	108.67	151.255	155
27	0.06	0.25	70	2.5	0.35	125.89	175.42	180
28	0.06	0.25	80	2.5	0.35	163.73	229.12	230
29	0.06	0.25	100	2.5	0.35	252.51	358	360
30	0.06	0.25	120	2.5	0.35	358.11	515.52	520
31	0.08	0.25	65	2.5	0.35	144.90	151.255	155
32	0.08	0.25	70	2.5	0.35	167.86	175.42	180
33	0.08	0.25	80	2.5	0.35	218.31	229.12	230
34	0.08	0.25	100	2.5	0.35	336.68	358	360
35	0.08	0.25	120	2.5	0.35	477.47	515.52	520
36	0.1	0.25	65	2.5	0.35	181.12	151.255	155
37	0.1	0.25	70	2.5	0.35	209.82	175.42	180
38	0.1	0.25	80	2.5	0.35	272.89	229.12	230
39	0.1	0.25	100	2.5	0.35	420.85	358	360
40	0.1	0.25	120	2.5	0.35	596.84	515.52	520
41	0.04	0.5	65	2.5	0.35	66.79	151.255	155
42	0.04	0.5	70	2.5	0.35	79.24	175.42	180
43	0.04	0.5	80	2.5	0.35	106.04	229.12	230
44	0.04	0.5	100	2.5	0.35	167.23	358	360
45	0.04	0.5	120	2.5	0.35	238.55	515.52	520

46	0.06	0.5	65	2.5	0.35	108.67	151.255	155
47	0.06	0.5	70	2.5	0.35	125.89	175.42	180
48	0.06	0.5	80	2.5	0.35	163.73	229.12	230
49	0.06	0.5	100	2.5	0.35	252.51	358	360
50	0.06	0.5	120	2.5	0.35	358.11	515.52	520
51	0.08	0.5	65	2.5	0.35	144.90	151.255	155
52	0.08	0.5	70	2.5	0.35	167.86	175.42	180
53	0.08	0.5	80	2.5	0.35	218.31	229.12	230
54	0.08	0.5	100	2.5	0.35	336.68	358	360
55	0.08	0.5	120	2.5	0.35	477.47	515.52	520
56	0.1	0.5	65	2.5	0.35	181.12	151.255	155
57	0.1	0.5	70	2.5	0.35	209.82	175.42	180
58	0.1	0.5	80	2.5	0.35	272.89	229.12	230
59	0.1	0.5	100	2.5	0.35	420.85	358	360
60	0.1	0.5	120	2.5	0.35	596.84	515.52	520
61	0	-	65	2.5	0.35	-	151.255	155
62	0	-	70	2.5	0.35	-	175.42	180
63	0	-	80	2.5	0.35	-	229.12	230
64	0	-	100	2.5	0.35	-	358	360
65	0	-	120	2.5	0.35	-	515.52	520