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RUNWAY AND HIGHWAY GEOMETRIC DESIGN WITH CONSIDERATION OF HYDROPLANING RISK

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Abstract: Runway is multilane high speed corridor. Width of runway varies from 23 m to 60 m. An important aspect of runway and highway geometric design is ensuring prompt removal of water from the runway / highway to reduce skidding and hydroplaning risks of aircraft /highway traffic operating under wet-weather conditions. A methodology for runway and highway geometric design that incorporates hydroplaning consideration has been proposed to ensure safe operations. Cross-slope is the main geometric element affected by the hydroplaning consideration. This paper presents an independent simplified methodology for risk calculation against hydroplaning. This methodology determines whether a trial geometric design catering to the aircraft traffic and highway traffic meets the safety requirement against hydroplaning for the selected design rainfall. Critical texture depth has been found to be 0.5mm for airport pavement to avoid hydroplaning. Provision of side slope on one side is safer than that on both sides with regard to hydroplaning risk. Hydroplaning risk increases with increasing cross-slope of the runway for a known texture depth. Hydroplaning risk in highway is minimal and risk may be minimized by limiting vehicle speed to 40 kmph or lesser during raining.

Keywords: *Hydroplanning, airport, highway, hydroplanning risk*

1.0 Introduction

1.1 Runway

Hydroplaning risk is defined as the probability of landing speed of the aircraft exceeding the computed hydroplaning speed. One of the important aspects of airport runway/highway geometric design is to ensure rapid removal of water from the runway to reduce hydroplaning and skidding risks of the aircraft operating under wet-weather conditions (Ashford and Wright 1992, FAA 2006). Hydroplaning of an aircraft refers to the condition when water on a wet runway is not displaced at a rate fast enough from the tire–pavement contact area of a rolling or a locked sliding tire, resulting in the tire not making contact with the pavement surface over its complete footprint area (Horne and

Joyner 1965). For this situation to occur, the amount of fluid encountered by the tire must exceed the combined drainage capacity of tire tread pattern and pavement macro-texture. In addition, the velocity of the aircraft must be sufficiently high so that the uplift force developed in the film of fluid is comparable to the tire inflation pressure. This causes the tire surface to buckle, thereby producing a large region of fluid capable of supporting the loaded tire. The uplift force of the fluid causes a loss of contact between the tire and the pavement, resulting in a low (or near zero) coefficient of friction and a loss of braking ability (Horne and Joyner 1965).

Runway geometric design guideline does not consider hydroplaning risk into consideration. Factors of hydroplaning are runway/highway cross-slope, texture depth and rainfall intensity. A probabilistic approach has been adopted to handle the aircraft types expected to operate in an airport, each with its own characteristic distribution of aircraft loading characteristics and landing speed. For each trial runway geometric design, the distribution of surface runoff water-film thickness over the runway width has been first calculated for the selected design rainfall.

Current airport geometric design methods do not explicitly consider hydroplaning risk, and the adequacy of runway geometric design and the associated drainage system against hydroplaning has not been evaluated. In recognition of the need for a design procedure to ensure safe aircraft operations, a framework for runway geometric design that incorporates hydroplaning consideration is proposed. Runway cross-slope is the main runway geometric element affected by the hydroplaning consideration. The proposed framework involves adding an independent module for hydroplaning risk calculation to determine whether a trial runway geometric design meets the safety requirement against hydroplaning for the selected design rainfall and aircraft traffic. For a trial runway geometric design, taking into account the probabilistic distributions of aircraft characteristics, landing speed, and aircraft wander, the level of hydroplaning risk can be computed by comparing the landing speed at each point on the width of the runway with the corresponding estimated hydroplaning speed. The hydroplaning speed at each point of interest is estimated by using an analytical computer simulation model. A numerical example is presented to illustrate the application of the proposed procedure (Ong and Fwa 2009).

The water-film thickness at any point on the runway/highway can be determined using the one-dimensional steady-state kinematic wave theory (Anderson, 1998), as follows:

$$t_x = \left[\frac{nL_x I}{105.425 S^{0.5}}\right]^{0.6} - MTD \qquad (1)$$

Where,
tx = Water-film thickness in mm at point x;
n = Manning coefficient of pavement surface roughness;

Lx = Flow length in m which is equal to the distance of point x from the runway centerline,
I = Rainfall intensity in mm/h;
S = Surface slope in m/m, and;
MTD = Mean texture depth of the pavement in mm.

Hydroplaning speed variation along the runway width for each aircraft type can be determined using following equation for air craft traffic:

$$Vp = 6.82\gamma(Pt)^{0.5}(tw)^{-0.037} \tag{2}$$

Where,
Vp = Hydroplaning Speed in km/hq;
Pt = Tire inflation pressure in KPa;
Tw = Water film thickness in mm and;
γ = Factor accounting for pavement average surface texture depth defined by Eq 3.

$$\gamma = e^{MTD(0.8436MTD-0.067)} \tag{3}$$

2.0 Tire Inflation Pressure and Wheel Load

Besides water-film thickness, the hydroplaning speed of an aircraft is affected by its tire inflation pressure and wheel load. The magnitudes of tire inflation pressure and wheel loads of all wheels can be established once the aircraft has been identified in the analysis. Because both tire inflation pressures and wheel loads depend on the type of the aircraft, it is necessary to analyze the hydroplaning risk of each type separately. For any given aircraft type, there would be variations in wheel loads and tire inflation pressure during actual operations. Although there might not be much variation in the tire inflation pressure of an aircraft type, the variations in wheel loads can be large. Aircraft wheel loads depend on not only the aircraft dead weight but also on the number of passengers, the amount of freight, and the fuel carried by the aircraft during landing or takeoff. In the framework proposed here, the probabilistic distribution of the magnitude of wheel load by aircraft type is considered.

3.0 Aircraft Landing Speed

The landing speed of aircraft varies over a rather large range, from 90 to 170 knots (Helleberg 2006). For present study landing speeds of 140 and 158 knots have been considered for Airbus A 320 and Boeing 747-400 with standard deviation of speeds 13 km/hr. and 15 km/hr. for analysis. Tire pressures of 1206 KPa 1380 KPa have been considered for both aircrafts for analysis.

4.0 Runway Width

The recommended runway widths are tabulated in Table 1. 7.5 m paved shoulder is generally provided on both sides of the runway. Considering paved shoulder, total runway width is 75 m (maximum) and runway width as mentioned in Table 1 has been considered for analysis.

Table 1: Runway Width

Code Number	Code Letter					
	A	B	C	D	E	F
1[a]	18 m	18 m	23 m			
2[a]	23 m	23 m	30 m			
3	30 m	30 m	30 m	45 m		
4			45 m	45 m	45 m	65 m

a. The width of a precision approach runway should not be less than 30 m where the code number is 1 or 2.
Note 1— The combinations of code numbers and letters for which widths are specified have been developed for typical aero-plane characteristics.
Note 2— Factors affecting runway width are given in the Aerodrome Design Manual, Part 1.

5.0 Highway

The hydroplaning model selected for PAVDRN was based upon the work of Gallaway et al. 1979 and Huebner et al. 1986. On the basis of the work reported by these authors, for water-film thickness less than 2.4 mm (0.095 in.), the hydroplaning speed is given by:

$$HPS = 26.04\ WFT - 0.259 \qquad (4)$$

Where
HPS = hydroplaning speed (mi/hr) and
WFT = water-film thickness (in.)

For water-film thickness greater than or equal to 2.4 mm (0.095 in.), the hydroplaning speed is

$$HPS = 3.09\ A \qquad (5)$$

Where A is the greater of the values calculated using Equations 6 and 7:

$$\frac{10.409}{WFT^{0.06}}+3.507 \tag{6}$$

$$[\frac{28.952}{WFT^{0.06}}-7.817]MDT^{0.14} \tag{7}$$

Where MTD is the mean texture depth (in.).

6.0 Concept of Hydroplaning Risk

The hydroplaning risk of an aircraft operating under a known set of conditions on a given runway can be computed as the probability that the operating speed of the aircraft / highway will reach or exceed its hydroplaning speed. Assuming that the probability density function f(v) of the spot speeds of the design aircraft type is known, the risk of hydroplaning α can be computed as follows:

$$\alpha = P(V > V_P)\text{=1-F(VP)} \tag{8}$$

Or

$$\alpha = 1-\int_0^v f(v)dv \tag{9}$$

Where,

v = Spot speed of the aircraft;
vp = Hydroplaning speed of the aircraft;
P(v > vp) = Probability of the aircraft having a landing or takeoff speed larger than the design hydroplaning speed;
f (v) = Probability density function of aircraft landing or takeoff speed and;
F(vp) = Cumulative probability of the aircraft with landing or takeoff speeds smaller than the design hydroplaning speed.

6.1 Proposed Methodology for Hydroplaning Risk

The proposed methodology to determine the hydroplaning risk isdescribed as follows:

1. Adopt average aircraft landing speed / highway speed and standard deviation of landing speed from each manual of aircraft and calculate coefficient of variation.

2. Determine hydroplaning speed at/ near center, 3.75, 7.5, 11.25, 15,--- 37.5m using Equations 2 and 4,5,6,7 for aircraft and highway traffic.

3. Determine normal deviate using following equation

$$1 - Zr = \frac{(V - Vp)}{\sigma v}$$

or

$$Zr = -1 + \frac{(Vp - V)}{\sigma v} \qquad (10)$$

Where,
Vp = Hydroplaning Speed at various locations;
V = Aircraft / highway vehicle Speed;
σ v = Standard deviation aircraft / highway vehicle speed.

4. From Zr, determine hydroplaning risk using Table 2.

5. Prepare table and graphs and analyse results.

6. Above procedure shall also be used for the determination of hydroplaning risk of highway traffic.

Table 2: Standard Normal Deviate Value Corresponding to Percentage of NPV <0

Standard Normal Deviate, Z	Probability of Risk (%)	Standard Normal Deviate, Z	Probability of Risk (%)	Standard Normal Deviate, Z	Probability of Risk (%)
0	50	1.2	11.5	2.4	0.82
0.10	46	1.3	9.7	2.5	0.62
0.20	42.1	1.4	8.1	2.6	0.47
0.30	38.2	1.5	6.7	2.7	0.35
0.40	34.5	1.6	5.5	2.8	0.26
0.50	30.9	1.7	4.5	2.9	0.19
0.60	27.4	1.8	3.6	3.0	0.13
0.70	24.2	1.9	2.9	3.1	0.10
0.80	21.2	2.0	2.3	3.25	0.06
0.90	18.4	2.1	1.8	3.5	0.023
1.00	15.9	2.2	1.4	4.0	0.003
1.10	13.6	2.3	1.1	4.99	0.00003

7.0 Presentation of Results and Analysis

7.1 Runway

Water film thickness and hydroplaning speed for Airbus A 320 have been determined using Equ.1 and Equ.2. One side and both side cambers have been considered for design. Texture depth (1.25 mm to 0.25 mm) and cross-fall (1.5 % to 2.5 %) have been varied in the analysis. The results are shown in Tables 3 and 4 for Airbus A 320 for one side camber. Hydroplaning Risk has been determined using Equ.4 for Airbus A 320 and Boeing 747-400. Table 5 presents hydroplaning risk for one side camber runway for both aircrafts . Table 6 presents hydroplaning risk for both side cambers runway for Boeing 747-400.

Table 3: Water Film Thickness for Air Bus 320 for One Side Camber of Runway

Dist. from One Edge(m)	Slope 1.5%					Slope 2.0%					Slope 2.5%				
	Texture Depth (mm)					Texture Depth (mm)					Texture Depth (mm)				
	1.25	1.00	0.75	0.50	0.25	1.25	1.00	0.75	0.50	0.25	1.25	1.00	0.75	0.50	0.25
3.75	0.57	0.82	1.07	1.32	1.57	0.42	0.67	0.92	1.17	1.42	0.31	0.56	0.81	1.06	1.31
7.50	2.39	2.64	2.89	3.14	3.39	2.09	2.34	2.59	2.84	3.09	1.87	2.12	2.37	2.62	2.87
11.25	4.20	4.45	4.70	4.95	5.20	3.75	4.00	4.25	4.50	4.75	3.43	3.68	3.93	4.18	4.43
15.00	6.02	6.27	6.52	6.77	7.02	5.42	5.67	5.92	6.17	6.42	4.99	5.24	5.49	5.74	5.99
18.75	7.84	8.09	8.34	8.59	8.84	7.09	7.34	7.59	7.84	8.09	6.55	6.80	7.05	7.30	7.55
22.50	9.66	9.91	10.16	10.41	10.66	8.76	9.01	9.26	9.51	9.76	8.11	8.36	8.61	8.86	9.11
26.25	11.48	11.73	11.98	12.23	12.48	10.42	10.67	10.92	11.17	11.42	9.67	9.92	10.17	10.42	10.67
30.00	13.29	13.54	13.79	14.04	14.29	12.09	12.34	12.59	12.84	13.09	11.23	11.48	11.73	11.98	12.23
33.75	15.11	15.36	15.61	15.86	16.11	13.76	14.01	14.26	14.51	14.76	12.79	13.04	13.29	13.54	13.79
37.50	16.93	17.18	17.43	17.68	17.93	15.43	15.68	15.93	16.18	16.43	14.35	14.60	14.85	15.10	15.35
41.25	18.75	19.00	19.25	19.50	19.75	17.10	17.35	17.60	17.85	18.10	15.91	16.16	16.41	16.66	16.91
45.00	20.57	20.82	21.07	21.32	21.57	18.76	19.01	19.26	19.51	19.76	17.47	17.72	17.97	18.22	18.47
48.75	22.39	22.64	22.89	23.14	23.39	20.43	20.68	20.93	21.18	21.43	19.03	19.28	19.53	19.78	20.03
52.50	24.20	24.45	24.70	24.95	25.20	22.10	22.35	22.60	22.85	23.10	20.59	20.84	21.09	21.34	21.59
56.25	26.02	26.27	26.52	26.77	27.02	23.77	24.02	24.27	24.52	24.77	22.15	22.40	22.65	22.90	23.15
60.00	27.84	28.09	28.34	28.59	28.84	25.43	25.68	25.93	26.18	26.43	23.71	23.96	24.21	24.46	24.71
63.75	29.66	29.91	30.16	30.41	30.66	27.10	27.35	27.60	27.85	28.10	25.27	25.52	25.77	26.02	26.27
67.50	31.48	31.73	31.98	32.23	32.48	28.77	29.02	29.27	29.52	29.77	26.83	27.08	27.33	27.58	27.83
71.25	33.29	33.54	33.79	34.04	34.29	30.44	30.69	30.94	31.19	31.44	28.39	28.64	28.89	29.14	29.39
75.00	35.11	35.36	35.61	35.86	36.11	32.11	32.36	32.61	32.86	33.11	29.95	30.20	30.45	30.70	30.95

Table 4: Hydroplaning Speeds for Air Bus 320 for One Side Camber of Runway

Dist. from One Edge(m)	Slope 1.5% Texture Depth (mm)					Slope 2.0% Texture Depth (mm)					Slope 2.5% Texture Depth (mm)				
	1.25	1.00	0.75	0.50	0.25	1.25	1.00	0.75	0.50	0.25	1.25	1.00	0.75	0.50	0.25
3.75	855	528	365	281	242	865	532	367	282	243	875	536	368	283	243
7.50	810	505	351	272	235	814	508	353	273	236	818	510	354	274	236
11.25	793	496	345	267	231	797	498	346	268	232	799	499	347	269	232
15.00	783	489	341	264	228	786	491	342	265	229	788	492	343	266	230
18.75	775	484	337	262	226	778	486	339	263	227	780	488	340	263	228
22.50	769	481	335	260	225	772	483	336	261	225	774	484	337	262	226
26.25	764	478	333	258	223	767	479	334	259	224	769	481	335	260	225
30.00	760	475	331	257	222	762	477	332	258	223	764	478	333	259	***224***
33.75	756	473	330	256	221	759	475	331	257	222	761	476	332	257	***223***
37.50	753	471	328	255	220	755	473	329	256	221	757	474	330	256	***222***
41.25	750	469	327	254	220	752	471	328	255	220	754	472	329	255	***221***
45.00	747	468	326	253	219	750	469	327	254	220	752	470	328	255	***220***
48.75	745	466	325	252	218	747	468	326	253	219	749	469	327	254	219
52.50	743	465	324	252	218	745	466	325	252	218	747	468	326	253	219
56.25	741	463	323	251	217	743	465	324	252	218	745	466	325	252	218
60.00	739	462	322	250	216	741	464	323	251	217	743	465	324	252	218
63.75	737	461	322	250	216	739	463	323	251	217	741	464	323	251	217
67.50	735	460	321	249	216	738	462	322	250	216	740	463	323	251	217
71.25	734	459	320	249	215	736	461	321	249	216	738	462	322	250	216
75.00	732	458	320	248	215	735	460	321	249	215	737	461	321	250	216

Table 5: Hydroplaning Risk for One Side Camber Provision on the Runway

Dist. from One Edge (m)	Probability of Risk of Hydro-Planning (%)					
	A 320 Air Bus			Boeing 747-400		
	Slope			Slope		
	1.5%	2.0%	2.5%	1.5%	2.0%	2.5%
3.75				3.600	4.500	5.500
7.50	49.000	48.400	45.700	0.820	1.100	3.250
11.25	34.600	38.200	40.000	0.350	0.350	0.470
15.00	27.500	29.000	30.900	0.130	0.200	0.260
18.75	21.200	24.000	24.200	0.100	0.130	0.130
22.50	15.100	18.300	21.200	0.060	0.070	0.100
26.25	13.800	15.900	17.200	0.040	0.040	0.090
30.00	11.700	13.600	14.800	0.030	0.035	0.060
33.75	10.100	11.500	12.500	0.023	0.023	0.030
37.50	8.900	9.700	11.100	0.010	0.023	0.023
41.25	8.000	8.900	9.700	0.001	0.010	0.023
45.00	6.900	8.100	7.700	0.001	0.010	0.015
48.75	6.500	6.700	8.000	0.001	0.010	0.010
52.50	5.500	6.500	6.900	0.002	0.010	0.009
56.25	5.000	5.600	6.500	0.002	0.010	0.008
60.00	4.500	5.500	5.700	0.002	0.005	0.007
63.75	4.100	4.500	5.400	0.002	0.004	0.006
67.50	3.500	4.400	4.600	0.003	0.004	0.006
71.25	3.200	4.000	4.500	0.003	0.003	0.006
75.00	2.800	3.600	4.000	0.003	0.003	0.003

Table 6 :Hydroplaning Risk for Boeing 747-400 for Runway with Both sides Camber

Dist. from Centre of Runway (m)	Slope		
	1.5%	2.0%	2.5%
3.75	3.600	4.500	5.500
7.50	0.820	1.100	3.250
11.25	0.350	0.350	0.470
15.00	0.130	0.200	0.260
18.75	0.100	0.130	0.130
22.50	0.060	0.070	0.100
26.25	0.040	0.040	0.090
30.00	0.030	0.035	0.060
33.75	0.023	0.023	0.030
37.50	0.010	0.023	0.023

7.2 Highway

Hydroplaning speed has been determined using Eqs. 5, 6 and 7 and presented in Table 7. Hydroplaning risks have been reported in Tables 8, 9 and 10 for different cross-slopes and design speeds.

Table 7: Hydroplaning Speeds on Highway for 2.5% Camber

Dist. from Centre(m)	Hydroplaning Speed(Kmph)							
	TD 0.5 mm	TD 0.75 mm	TD 1 mm	TD 1.25 mm	TD 1.5 mm	TD 2 mm	TD 3 mm	TD 4 mm
3.75	94.78	101.62	111.81	130.32	199.41	#NUM!	#NUM!	#NUM!
7.50	74.98	76.95	79.21	81.82	84.92	93.44	117.70	#NUM!
11.25	66.43	67.50	68.66	69.93	71.31	74.54	96.27	107.48
15.00	61.20	61.91	62.66	63.46	64.31	66.19	91.44	98.00
18.75	57.50	58.02	58.57	59.14	59.74	61.03	88.64	94.01
22.50	54.69	55.10	55.71	56.15	56.62	57.60	86.80	91.63

Table 8: Hydroplaning Risk for Design Speed 120 kmph (COV =0.05) Cross Slope 2.5%

Dist from Centre(m)	Hydroplaning Risk (%)							
	TD 0.5 mm	TD 0.75 mm	TD 1 mm	TD 1.25 mm	TD 1.5 mm	TD 2 mm	TD 3 mm	TD 4 mm
3.75	0.00003	0.00300	1.10000	24.2	0.00300	0.00300	0.00300	0.00300
7.50	0.00003	0.00300	0.00300	0.00003	0.00300	0.00300	9.60000	0.00300
11.25	0.00003	0.00300	0.00300	0.00003	0.00300	0.00300	0.00300	0.13000
15.00	0.00003	0.00300	0.00300	0.00003	0.00300	0.00300	0.00300	0.00300
18.75	0.00003	0.00300	0.00300	0.00003	0.00300	0.00300	0.00300	0.00300
22.50	0.00003	0.00300	0.00300	0.00003	0.00300	0.00300	0.00300	0.00300

Table 9: Design Speed 120 kmph (COV =0.05) Cross Slope 4 %

Dist from Centre(m)	Hydroplaning Risk (%)							
	TD 0.5 mm	TD 0.75 mm	TD 1 mm	TD 1.25 mm	TD 1.5 mm	TD 2 mm	TD 3 mm	TD 4 mm
3.75	0.0025	0.35	48	0.00003	0.00003	0.00003	0.00003	0.00003
7.50	0.00003	0.00003	0.00003	0.00003	0.00003	0.023	0.00003	0.00003
11.25	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.024	0.50138
15.00	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.003
18.75	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
22.50	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003

Table 10 Design Speed 60 kmph (COV =0.05) with 2.5% cross slope

Dist. from Centre(m)	Hydroplaning Risk (%)							
	TD 0.5 mm	TD 0.75 mm	TD 1 mm	TD 1.25 mm	TD 1.5 mm	TD 2 mm	TD 3 mm	TD 4 mm
3.75	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
7.50	0.00300	0.00200	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
11.25	13.6000	6.70000	2.90000	1.10000	0.26000	0.02600	0.00003	0.00003
15.00	27.4000	34.50000	0.47000	44.00000	34.90000	15.90000	0.00003	0.00003
18.75	3.70000	0.00003	6.80000	9.80000	15.90000	26.20000	0.00003	0.00003
22.50	0.26000	0.47000	0.82000	1.20000	1.80000	3.60000	0.00003	0.00003

8.0 Discussion

8.1 Runway

From Table 3, it has been found that for a known texture depth, water film thickness increases with increase of distance from runway center for both sides camber / from rising edge for one side camber of runway. For a known distance from runway center for both sides camber / one side camber, water film thickness increases with decreasing texture depth. Water film thickness decreases with increasing camber slope while values of other factors remain constant.

From Table 4, it has been found that for a known texture depth, hydroplaning speed decreases with increase of distance from runway center for both sides camber / from rising edge for one side camber of runway. Again, for a known distance from runway center for both sides camber / one side camber, hydroplaning speed decreases with decreasing texture depth. Hydroplaning speed decreases with increasing camber slope while values of other factors remain constant. From Table 4, it is also found that hydroplaning speed is on the higher side compared to landing speed. Therefore, a texture depth of more than 0.5 mm is safer from hydroplaning risk. Critical texture for hydroplaning is 0.5 mm and below. Therefore, it is suggested to keep a minimum of 0.5 mm of texture depth for runway pavement.

Hydroplaning risk has been calculated for texture depth 0.5 mm and presented in Table 5. From Table 5, it is found that hydroplaning risk decreases with increasing distance from center line/ rising edge for both sides / one side camber of runway. From Table 6, it is also found that hydroplaning risk increases with increasing cross-slope. Typical tire impression of aircraft on the runway is shown in Fig. 1. From these photographs, it has been found that most of aircrafts use 15 m width (7.5 m both sides of the center line of runway) for landing purposes. Therefore, the width of 15 m width is very critical for hydroplaning and pavement thickness design. Cross-slope of runway may be both sides and one side. Therefore, hydroplaning risk for this 15 m may be considered for hydroplaning design and pavement thickness. Special care should be given during geometric and pavement design.

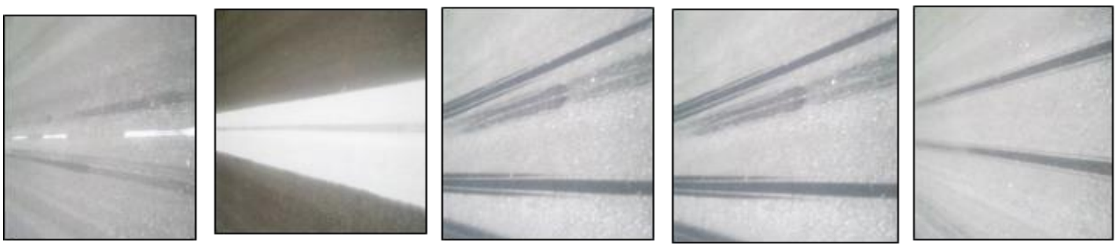

Fig. 1: Landing Location of Aircraft on Runway

8.2 Highway

From Table 7, it is found that hydroplaning speed increases with increase texture depth at known distance of highway from the center of the highway.

From Tables 8 and 9, it is observed that hydroplaning risk is minimal at vehicle speed of 120 kmph.
Hydroplaning risk is prone for vehicles travelling at speed of 60 kmph and maintaining distance of 11.25 and 15 m from center of highway for camber values of 2.5% and 4 % respectively.

Hydroplaning risk is found at 0.00003 % i.e., minimal risk at vehicle speed of 40 kmph and below. Therefore, hydroplaning risk may be reduced by reducing speed to40 kmph or lower.

9.0 Conclusions

Current runway geometric design procedures do not consider the risk of hydroplaning. A methodology has been presented for incorporating hydroplaning risk consideration into airport runway geometric design. This is achieved by simplified risk analysis for hydroplaning risk calculation to the conventional design procedure. This model calculates the hydroplaning risk of the trial design and determines whether it meets the safety requirement against hydroplaning for the selected design rainfall and aircraft traffic. The proposed procedure for hydroplaning risk calculation adopts a probabilistic approach. It takes into account the probabilistic distributions of aircraft operating characteristics such as tire inflation pressure as well as the probabilistic distributions of landing speed. The additional component of hydroplaning risk consideration represents a refinement to current runway geometric design practices and helps to address an aircraft operational safety issue that has not previously been considered in the conventional design methods. Following conclusions may be drawn from this present study:

9.1 Runway

- Hydroplaning design shall be considered for the texture depth of 0.5 mm or below.
- Critical location for hydroplaning design is 7.5 m on both sides of the center line of runway width.
- Water film thickness increases with increase of distance from runway center for both sides camber / from rising edge for one side camber of runway for a known texture depth and vice versa for hydroplaning speed.

- Hydroplaning risk can be minimized by increasing texture depth to 0.5 mm and more.
- Retexturing pavement is required when runway texture depth grinds below 0.5 mm.
- Provision of one side slope is safer for hydroplaning risk for critical width of 15m (7.5 m both sides of the runway centre).
- Hydroplaning risk increases with increasing cross-slope for a known texture depth.

9.2 Highway

- Runways are more prone to hydroplaning risk than highways.
- Hydroplaning risk is minimal for vehicles operating at speed 40 kmph or below.

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