. 100, . 2, . 41– 50, 2010, 10.1 5/01200 0155

Short Note

m r r m 2

3 r

et al., 1 5 ; et al., 1 5 ; et al., 1 0 ; et al., 2001, 200 ; et al., 1 3, 1 ; et al., 2000 ; et al., 2004 ; 1 , 2001 ; Č r (1 , 2001) ; et al., 1 5 ; et al., 2001 ; et al., 2003, 2005 ; K m r r, 2005 ; , 200 ; et al., ; 1 5 r r, 1 2 ; et al., 2001, 200 , 200 ; et al., 200

, 1 3 *et al.*, 2001), (, 1 3), (K , 200), (, 1).

2 3

2 3 *et al.* (2001, 200 , 200). 2

B-

B- (, 1 1 *et al.*, 2001).

1 , 1 2).

et al. (200).

(. 4).

$$v(\ ) = v_0 + \ \mathbf{x}\ , \tag{1}$$

(1). $= -k$ ( ),

$= 0$.

$$t = \int \frac{ds}{v(\ )}. \tag{2}$$

(, 1).

$\mathbf{x}$ $\mathbf{y}$ (Č , 2001, 3. .2)

$$t(\ ,\mathbf{y}) = \frac{1}{k}\ \ p, \tag{3}$$

$$p = 1 + \frac{k^2 r^2}{2v(\ )v(\mathbf{y})}, \qquad r = \|\mathbf{x} - \mathbf{y}\|, \qquad k = \|\ \|. \tag{4}$$

( ).

(*et al.*, 1 0 *et al.*, 2001).

(Č r , 2001). (1). K r r (1 3). 2 (*et al.*, 2001) 3 (*et al.*, 200). *et al.*, 1 2), (m , r 1),

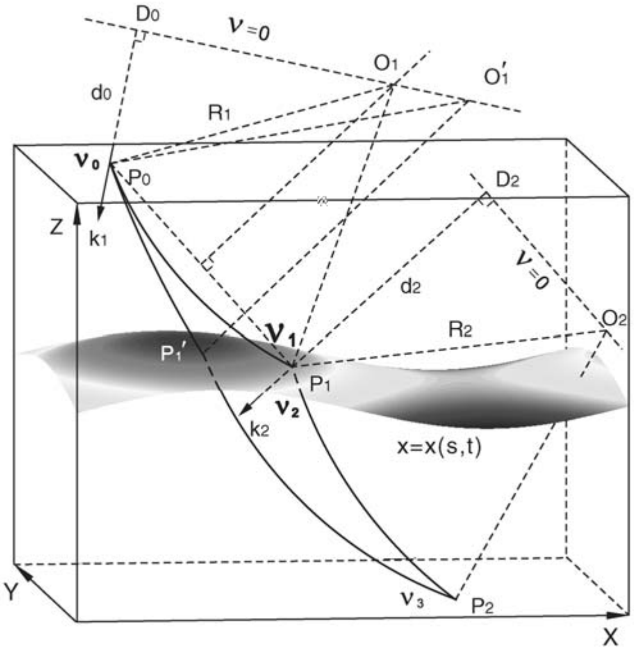
1, P_0, P_1, P_2 P_1

$$\mathbf{x} = \mathbf{x}(s, t). \quad (5)$$

P_0 P_2 $\mathbf{x}(\xi, \eta)$

$$T = t_1(P_0, \mathbf{x}) + t_2(\mathbf{x}, P_2). \quad (\ )$$

$(\xi + \Delta s, \eta + \Delta t)$



F 1. P_0P_1 P_1 O_1 $v = 0$ P_0P_1. $\mathbf{O}_1\mathbf{P}_0$, $\mathbf{O}_1\mathbf{P}_1$ P_1 P_1'

$$\left.\frac{\partial T}{\partial s}\right|_{(s=\xi+\Delta s, t=\eta+\Delta t)} = 0, \qquad \left.\frac{\partial T}{\partial t}\right|_{(s=\xi+\Delta s, t=\eta+\Delta t)} = 0. \quad (\ )$$

$$\begin{aligned}
&\frac{\partial T}{\partial x_i}x_{is} + \left(\frac{\partial^2 T}{\partial x_i \partial x_j}x_{is}x_{js} + \frac{\partial T}{\partial x_i}x_{iss}\right)\Delta s \\
&\quad + \left(\frac{\partial^2 T}{\partial x_i \partial x_j}x_{is}x_{jt} + \frac{\partial T}{\partial x_i}x_{ist}\right)\Delta t = 0, \\
&\frac{\partial T}{\partial x_i}x_{it} + \left(\frac{\partial^2 T}{\partial x_i \partial x_j}x_{it}x_{js} + \frac{\partial T}{\partial x_i}x_{its}\right)\Delta s \\
&\quad + \left(\frac{\partial^2 T}{\partial x_i \partial x_j}x_{it}x_{jt} + \frac{\partial T}{\partial x_i}x_{itt}\right)\Delta t = 0, \quad (\ )
\end{aligned}$$

i

$$\Delta s = \frac{U_{13}U_{22} - U_{23}U_{12}}{U_{11}U_{22} - U_{12}U_{21}},$$
$$\Delta t = \frac{U_{11}U_{23} - U_{21}U_{13}}{U_{11}U_{22} - U_{12}U_{21}}, \quad (\ )$$

$$
\begin{aligned}
U_{11} &= \frac{\partial^2 T}{\partial x_i \partial x_j} x_{is} x_{js} + \frac{\partial T}{\partial x_i} x_{iss}, \\
U_{12} &= \frac{\partial^2 T}{\partial x_i \partial x_j} x_{is} x_{jt} + \frac{\partial T}{\partial x_i} x_{ist}, \qquad U_{13} = -\frac{\partial T}{\partial x_i} x_{is}, \\
U_{21} &= \frac{\partial^2 T}{\partial x_i \partial x_j} x_{it} x_{js} + \frac{\partial T}{\partial x_i} x_{its}, \\
U_{22} &= \frac{\partial^2 T}{\partial x_i \partial x_j} x_{it} x_{jt} + \frac{\partial T}{\partial x_i} x_{itt}, \qquad U_{23} = -\frac{\partial T}{\partial x_i} x_{it}, \\
x_{is} &= \frac{\partial x_i}{\partial s}, \qquad x_{it} = \frac{\partial x_i}{\partial t}, \qquad x_{iss} = \frac{\partial^2 x_i}{\partial s^2}, \\
x_{ist} &= x_{its} = \frac{\partial x_i}{\partial s}\frac{\partial x_i}{\partial t}, \qquad x_{itt} = \frac{\partial^2 x_i}{\partial t^2}.
\end{aligned} \tag{10}
$$

... $(\xi + \Delta s, \eta + \Delta t)$ ... (ξ, η) ... $f(x, y, z) = 0$, ... $s = x, t = y$, ...

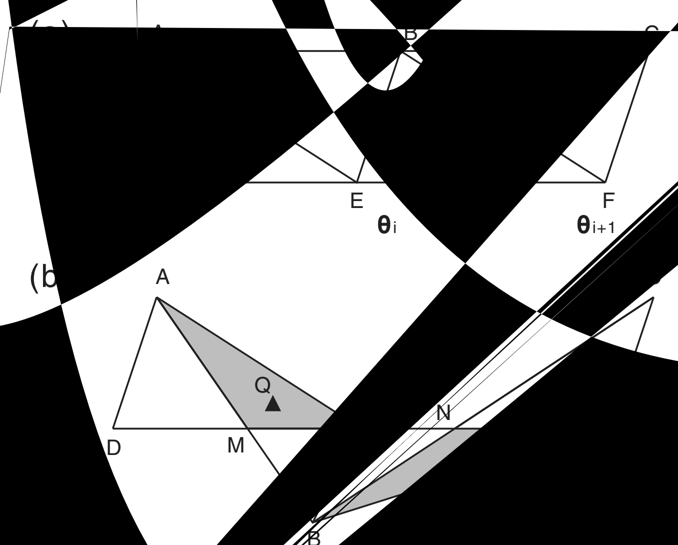
$$
\begin{aligned}
& x_{1s} = 1, \quad x_{2s} = 0, \quad x_{3s} = \frac{\partial z}{\partial x}, \\
& x_{1t} = 0, \quad x_{2t} = 1, \quad x_{3t} = \frac{\partial z}{\partial y}, \\
& x_{iss} = x_{ist} = x_{its} = x_{itt} = 0, \quad (i = 1, 2), \\
& x_{3ss} = \frac{\partial^2 z}{\partial x^2}, \quad x_{3st} = x_{3ts} = \frac{\partial^2 z}{\partial x \partial y}, \quad x_{3tt} = \frac{\partial^2 z}{\partial y^2}.
\end{aligned} \tag{11}
$$

... (*et al.*, 200). ... (n_1, n_2, n_3), ... (n_1, n_2, n_3) ... $_2(-\frac{\partial z}{\partial x}, -\frac{\partial z}{\partial y}, 1)$ ...

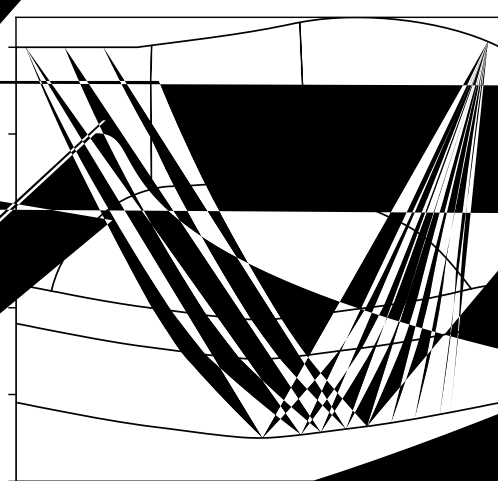
$$
\frac{\partial z}{\partial x} = -\frac{n_1}{n_3}, \qquad \frac{\partial z}{\partial y} = -\frac{n_2}{n_3}. \tag{12}
$$

... n_3 ...

... (10) ...



(b)
A
B
C
D
E
F
M
N
Q
θi
θi+1



2 … P … (et al., 200), … (50–100).

… (et al., 200). (3, 4, 5) … 2 … 3 …

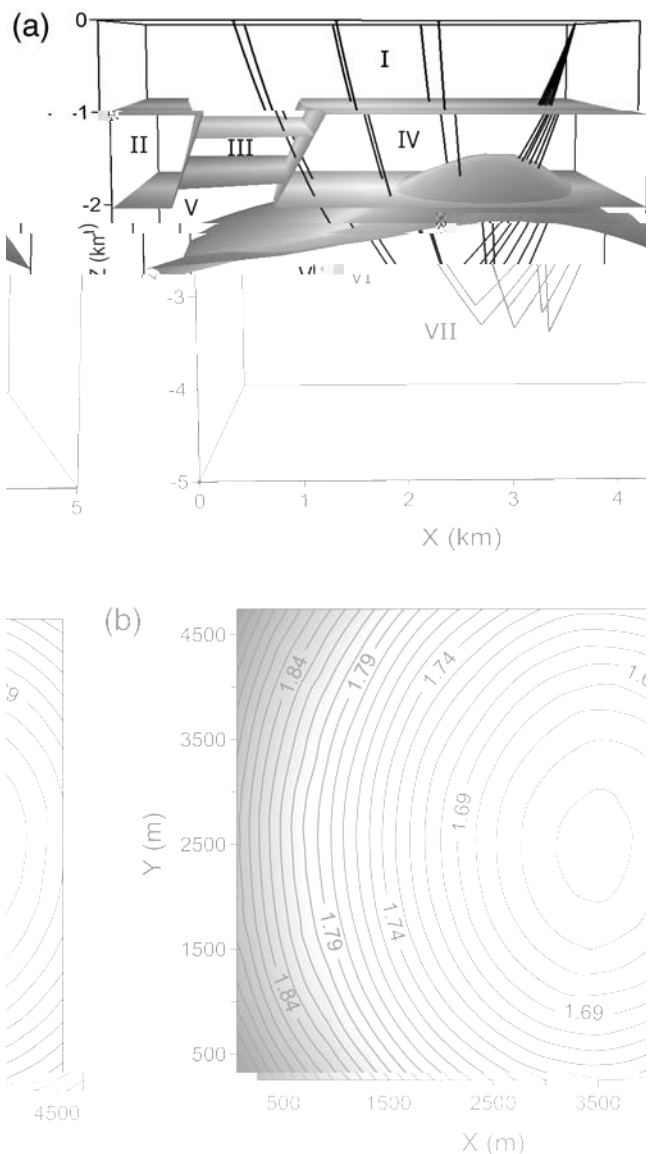


Figure 4. (a) … (2) … 2 … (b) …

2 … 3 …

3 … 2 (1) … 5000 5000 m. … 2 … 3 … 33 m. … 1 … 1.

… v_0 … $\mathbf{x}_0\,(x_0, z_0)$, … k, … θ … 0 … 30. … 3 … x- …

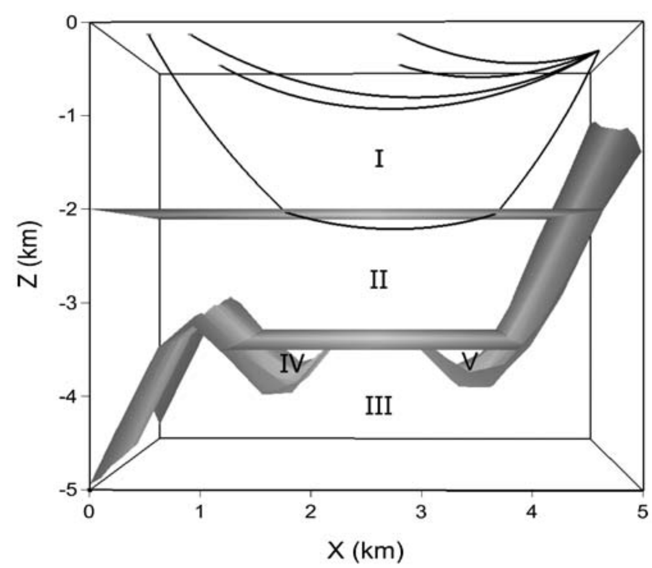


Figure 5. … (3) … 4 …

2

3 r m r * f 2

V_0, m/	X_0, m	Y_0, m	Z_0, m	k, $^{-1}$	θ,	ϕ,
3000	2500	2500	0	0.	1 0	0
3 00	250	2500	−1000	0.	1 0	1 0
4000	1250	2500	−1250	0.5	1 0	1 0
3 00	3500	2500	−1000	0.	1 5	355
4 00	1000	2500	−2000	0.5	1 5	5
5 00	2500	2500	−2000	0.	1 0	0
500	2500	2500	−3700	0.	1 0	0

* 1 f r f f r m r . r f r r f θ, r fr m 0 1 0, m ϕ, r fr m 0 3 0.

, r 4 m m (2), m- f rm f , , r r f , , r, m , f 5000 5000 5000 m. 2 , 4 4 r , 2152 . r m- r m r r m , m r r f 2. r f r f θ r fr m 0 1 0, m ϕ r fr m 0 3 0. , r rf f f r f rf , r 4 r

r , r - m . x- y- r r f r r . , (3) , , r - m . r , m- r , m (3, . 5) r f r , r r . 5 , 3 35 r , 1 1 . r m- r f r 4 f 2. r r , r , r 5. f , r r r . r , r 00 r r (20 40 r) r , rf . m (, m- , 1.) f r 2 .4 , r f 0.5 m, f r 14. 2 m r , f r . r f f r m f , r , r r r , f f f r r m r .

, r f r r f m , m r r r r , m . r , m m r r m r r

3

r , r r r * f 2

, m r	X_0, m	Y_0, m	Z_0, m	, m r	V_0, m/	m r

r r r

m f r

m f f r f r r m

m m r

r m r f m r

m r r m

r m r f r r

r r m r m r

ff m m m r r

m 2 3 r m

r

r m fr m r

r f r

m

r f f f

r f (40 21003, 40 30315, 40 4041, 4040400), r r (r -02-02),

m f (K 2- -132), r f r m

& f f m r

(0 11), K r r m f

m f r r f r m

r r f r r mm r f r m r

m f m r r f

r f r f

m r f r

f r

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1 P_0 P_1 1, P_0P_1 O_1 *et al.*, 1 0 , 2005), O_1 $v = 0$ P_0P_1. d_0 P_0

$$d_0 = \frac{v_0}{k_1}. \quad (1)$$

O_1 $\mathbf{P_0P_1}$ C

$$\|\mathbf{O_1P_0}\| = R_1, \quad \|\mathbf{O_1P_1}\| = R_1, \quad \mathbf{P_0O_1} \quad \mathbf{P_0D_0} = d_0^2, \quad (\mathbf{O_1P_0} \quad \mathbf{O_1P_1}) = 0. \quad (2)$$

P_0P_1

$$\|\mathbf{O_1} \quad \| = R_1. \quad (3)$$

P_0P_1 $\mathbf{P_0P_1}$

$$\mathbf{x}(- \mathbf{x}_0) \; (\; \mathbf{P_0P_1}) = 0. \quad (4)$$

3

1 P_1. (5) (1, 0), (0, 1), (0, 0) 2 1 P_0 v_0 P_2 v_3, v_1 v_2 P_1

$$T = t(P_0, P_1) + t(P_1, P_2) = \frac{1}{k_1} \quad p_1 + \frac{1}{k_2} \quad p_2, \quad (1)$$

$$p_1 = 1 + \frac{k_1^2 r_1^2}{2v(\mathbf{x}^{(1)})v(\mathbf{x}^{(2)})}, \qquad p_2 = 1 + \frac{k_2^2 r_2^2}{2v(\mathbf{x}^{(2)})v(\mathbf{x}^{(3)})}, \quad (1)$$

$$k_1 = \| \; _1\|, \quad k_2 = \| \; _2\|, \quad r_1 = \|\mathbf{x}^{(2)} - \mathbf{x}^{(1)}\|, \quad r_2 = \|\mathbf{x}^{(2)} - \mathbf{x}^{(3)}\|. \quad (2)$$

$$\left.\frac{\partial T}{\partial s}\right|_{(s=s*,t=t*)} = 0, \qquad \left.\frac{\partial T}{\partial t}\right|_{(s=s*,t=t*)} = 0, \quad (3)$$

s^* t^*

$$\left.\left(k_2\sqrt{p_2^2-1}\frac{\partial p_1}{\partial s} + k_1\sqrt{p_1^2-1}\frac{\partial p_2}{\partial s}\right)\right|_{(s=s*,t=t*)} = 0,$$
$$\left.\left(k_2\sqrt{p_2^2-1}\frac{\partial p_1}{\partial t} + k_1\sqrt{p_1^2-1}\frac{\partial p_2}{\partial t}\right)\right|_{(s=s*,t=t*)} = 0. \quad (4)$$

(4)

$$
\begin{aligned}
&\sqrt{p_1^2-1}|_{(s=s*,t=t*)} \\
&\quad = \sqrt{p_1^2-1} + \frac{p_1}{\sqrt{p_1^2-1}}\frac{\partial p_1}{\partial x_i}(x_{is}\Delta s + x_{it}\Delta t), \\
&\left.\frac{\partial p_1}{\partial s}\right|_{(s=s*,t=t*)} \\
&\quad = \frac{\partial p_1}{\partial x_i}x_{is} + \left(\frac{\partial^2 p_1}{\partial x_i \partial x_j}x_{is}x_{js} + \frac{\partial p_1}{\partial x_i}x_{iss}\right)\Delta s \\
&\qquad + \left(\frac{\partial^2 p_1}{\partial x_i \partial x_j}x_{is}x_{jt} + \frac{\partial p_1}{\partial x_i}x_{ist}\right)\Delta t.
\end{aligned}
\tag{5}
$$

f r r r r .
m , (4) r , ,
(5). , (4) r
fr r r r, r r , , m r, r
f rm,

$$
\Delta s = \frac{U_{13}U_{22} - U_{23}U_{12}}{U_{11}U_{22} - U_{12}U_{21}}, \qquad \Delta t = \frac{U_{11}U_{23} - U_{21}U_{13}}{U_{11}U_{22} - U_{12}U_{21}},
\tag{ }
$$

r

$$
\begin{aligned}
U_{11} &= k_2(e_2A_s^{(1)}A_s^{(3)} + f_2B_{ss}^{(1)}) + k_1(e_1A_s^{(1)}A_s^{(3)} + f_1B_{ss}^{(3)}), \\
U_{12} &= k_2(e_2A_s^{(1)}A_t^{(3)} + f_2B_{st}^{(1)}) + k_1(e_1A_t^{(1)}A_s^{(3)} + f_1B_{st}^{(3)}), \\
U_{13} &= -(k_2f_2A_s^{(1)} + k_1f_1A_s^{(3)}), \\
U_{21} &= k_2(e_2A_t^{(1)}A_s^{(3)} + f_2C_{ts}^{(1)}) + k_1(e_1A_s^{(1)}A_t^{(3)} + f_1C_{ts}^{(3)}), \\
U_{22} &= k_2(e_2A_t^{(1)}A_t^{(3)} + f_2C_{tt}^{(1)}) + k_1(e_1A_t^{(1)}A_t^{(3)} + f_1C_{tt}^{(3)}), \\
U_{23} &= -(k_2f_2A_t^{(1)} + k_1f_1A_t^{(3)}), \qquad e_1 = \frac{p_1}{\sqrt{p_1^2-1}}, \\
e_2 &= \frac{p_2}{\sqrt{p_2^2-1}}, \qquad f_1 = \sqrt{p_1^2-1}, \qquad f_2 = \sqrt{p_2^2-1}, \\
A_s^{(1)} &= Q_i^{(1)}x_{is}^{(2)}, \qquad A_t^{(1)} = Q_i^{(1)}x_{it}^{(2)}, \qquad A_s^{(3)} = Q_i^{(3)}x_{is}^{(2)}, \\
A_t^{(3)} &= Q_i^{(3)}x_{it}^{(2)}, \qquad B_{ss}^{(1)} = Q_i^{(1)}x_{iss}^{(2)} + R_{ij}^{(1)}x_{is}^{(2)}x_{js}^{(2)}, \\
B_{st}^{(1)} &= Q_i^{(1)}x_{ist}^{(2)} + R_{ij}^{(1)}x_{is}^{(2)}x_{jt}^{(2)}, \\
B_{ss}^{(3)} &= Q_i^{(3)}x_{iss}^{(2)} + R_{ij}^{(3)}x_{is}^{(2)}x_{js}^{(2)}, \\
B_{st}^{(3)} &= Q_i^{(3)}x_{ist}^{(2)} + R_{ij}^{(3)}x_{is}^{(2)}x_{jt}^{(2)}, \\
C_{ts}^{(1)} &= Q_i^{(1)}x_{its}^{(2)} + R_{ij}^{(1)}x_{it}^{(2)}x_{js}^{(2)}, \\
C_{tt}^{(1)} &= Q_i^{(1)}x_{itt}^{(2)} + R_{ij}^{(1)}x_{it}^{(2)}x_{jt}^{(2)}, \\
C_{ts}^{(3)} &= Q_i^{(3)}x_{its}^{(2)} + R_{ij}^{(3)}x_{it}^{(2)}x_{js}^{(2)}, \\
C_{tt}^{(3)} &= Q_i^{(3)}x_{itt}^{(2)} + R_{ij}^{(3)}x_{it}^{(2)}x_{jt}^{(2)},
\end{aligned}
\tag{ }
$$

$$
\begin{aligned}
Q_i^{(1)} &= \frac{k_1^2}{2v_0}\frac{2(x_i^{(2)} - x_i^{(1)})v_1 - r_1^2k_i^{(1)}}{v_1^2}, \\
Q_i^{(3)} &= \frac{k_2^2}{2v_3}\frac{2(x_i^{(2)} - x_i^{(3)})v_2 - r_2^2k_i^{(2)}}{v_2^2}, \\
R_{ij}^{(1)} &= \frac{k_1^2}{v_0}\left(\frac{\delta_{ij}v_1 - (x_i^{(2)} - x_i^{(1)})k_j^{(1)} - (x_j^{(2)} - x_j^{(1)})k_i^{(1)}}{v_1^2}\right. \\
&\qquad \left. + \frac{r_1^2k_i^{(1)}k_j^{(1)}}{v_1^3}\right), \\
R_{ij}^{(3)} &= \frac{k_2^2}{v_3}\left(\frac{\delta_{ij}v_2 - (x_i^{(2)} - x_i^{(3)})k_j^{(2)} - (x_j^{(2)} - x_j^{(3)})k_i^{(2)}}{v_2^2}\right. \\
&\qquad \left. + \frac{r_2^2k_i^{(2)}k_j^{(2)}}{v_2^3}\right), \\
k_i^{(1)} &= {}_1 \quad {}_i, \qquad k_i^{(2)} = {}_2 \quad {}_i, \qquad v_0 = v_0(\ ^{(1)}), \\
v_1 &= v_1(\ ^{(2)}), \qquad v_2 = v_2(\ ^{(2)}), \qquad v_3 = v_3(\ ^{(3)}), \\
\delta_{ij} &= \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases}, \quad x_{is}^{(2)} = \frac{\partial x_i^{(2)}}{\partial s}, \quad x_{it}^{(2)} = \frac{\partial x_i^{(2)}}{\partial t}, \\
x_{iss}^{(2)} &= \frac{\partial^2 x_i^{(2)}}{\partial s^2}, \qquad x_{ist}^{(2)} = x_{its}^{(2)} = \frac{\partial^2 x_i^{(2)}}{\partial s \partial t}, \\
x_{itt}^{(2)} &= \frac{\partial^2 x_i^{(2)}}{\partial t^2}
\end{aligned}
\tag{ }
$$

K r r f r ,
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, , , 23002
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(. .)

, r r 2 , 200